UNIVERSITÉ DE MONTRÉAL

LOCATION MANAGEMENT METHODS IN TD-SCDMA

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IN TD-SCDMA

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RESUMÉ

L'algorithme de routage basé sur la localisation nous permet de réduire la surcharge de trafic de signalisation dans le réseau ad hoc. Ce type d'algorithme existant souvent utilise le système de positionnement global (GPS) comme leur fournisseur d'information de position. Mais nous observons également beaucoup de limitations de ces algorithmes. Tout d'abord, l'utilisation du GPS n'est pas réaliste et seulement disponible dans certaines circonstances. Deuxièmement, la synchronisation d'information de position dans le réseau ad hoc soulève la surcharge de trafic de signalisation, par conséquent diminue la rentabilité de ces algorithmes.

L'objectif de notre recherche est de développer un nouvel algorithme qui pourrait profiter pleinement d'information de position, tandis qu'éviter les inconvénients mentionnés ci-dessus. Ce travail propose d'employer la position locale au lieu de la position globale dans l'algorithme proposé. L'algorithme de routage conçu est prototypé de l'algorithme de routage Ad-Hoc On-demande Distance Vecteur (AODV). En plus, il synchronise l'information de position réactivement. Des antennes intelligentes sont utilisées pour obtenir l'information de position locale, donc cet algorithme est indépendant du GPS. L'algorithme emploie des algorithmes ad hoc de position pour établir des coordonnées locales du réseau, et adapte de nouvelles stratégies pour réduire la surcharge de trafic de signalisation contrôle.

Un ensemble d'expériences est conçu pour évaluer la performance de cet algorithme. Les résultats de simulation prouvent que le nouvel algorithme de routage réduit la surcharge de trafic de signalisation contrôle du réseau et la consommation d'énergie. Il améliore également le débit moyen du réseau. Tous ceux-ci sont implémentés sans augmenter le délai moyen du réseau ad hoc.

ABSTRACT

Location-based routing algorithms are promising in reducing the overhead of routing in ad hoc network. Existing location-based routing algorithms employ the Global Positioning System (GPS) as their location information provider, and synchronize the information network-wide. But we also see many limitations of these protocols. First of all is the use of GPS is not realistic and only available in certain circumstances. Second is the synchronizing of the location information in the ad hoc network raises overhead, and hence decreases the usability of these algorithms.

The objective of this work is to develop a novel algorithm that could take full advantages of the location information, while avoid the disadvantages mentioned above. This work proposes to use local position instead of global position in location-based algorithms. The conceived routing algorithm is prototyped from the Ad-Hoc On-demand Distance Vector (AODV) routing algorithm. Hence it synchronizes the location information reactively. Smart antennas are employed to obtain local position information; hence the algorithm is freed from GPS. The algorithm applies ad hoc position algorithms to build local network coordinates, and adapts new strategies to reduce control overhead.

A set of experiments is designed to evaluate the algorithm's performance. Simulation results show that the novel routing algorithm successfully reduces the network control overheads and the power consumption. It also improves network average throughput. All these achievements are at no expense of other performances.

CONDENSÉ EN FRANÇAIS

1. INTRODUCTION

Ad hoc est une expression latine qui signifie *pour ceci [but]*. Ceci bien explique comment le réseau s'appelle. Un réseau Ad Hoc est donc un réseau sans fil qui ne nécessite aucune infrastructure fixe et aucun support administratif pour opérer. C'est un réseau dont la topologie est variable dans le temps du fait de la mobilité de ses composants (à un moment donné, un mobile peut rejoindre ou quitter le réseau Ad Hoc existant). Ce type de réseau maintenant est connu sous le nom de réseau ad hoc mobile (MANET). Un réseau ad hoc se compose d'un groupe de noeuds mobiles. Entre chaque deux noeuds, la communication est effectuée par la radio. Tous les noeuds dans le réseau sont des noeuds d'épine dorsale, ceci signifie qu'ils sont en tant que aiguilleurs aussi bien que abonnés simultanément. Mais en raison du mouvement des noeuds, la conduite de la topologie devient incertaine dans le réseau.

2. PROBLÈME D'ADRESSAGE

Un des inconvénients importants du protocole de routage dans les réseaux ad hoc est que la performance dégrade dû au contrôle de la surcharge de trafic de la signalisation. Les surcharges de trafic de la signalisation sont des messages générés de la gestion de routage du réseau ad hoc. Deux caractéristiques du réseau ad hoc contribuent à ceci-- la topologie dynamique et le cheminement de multi sauts. Les surcharges de trafic de la signalisation peuvent mener aux graves problèmes suivants :

- Dégradation de la qualité de service du réseau ad hoc.
- le temps moyen d'attente est long pour la transmission de paquets,
- le taux de la perte de données est élevé,
- le débit du réseau est faible,

- aucune garantie de la communication de bout en bout,

Les problèmes au-dessus ne sont pas acceptables mais se produits dans les réseaux ad hoc.

3. OBJECTIFS DE RECHERCHE

Compte tenu des difficultés énoncées précédemment, nous visons trouver une solution pour le problème d'adressage du réseau ad hoc, le protocole proposé est un protocole de routage basé sur la position locale. Le nouveau protocole de routage du réseau ad hoc conçu possède les propriétés suivantes :

- Basé sur la position locale,
- Indépendant de GPS,
- Synchronisez l'information de position seulement sur demande,
- Réduisez la surcharge de trafic de la signalisation,
- Conserver de l'alimentation, et
- Améliorez la performance du réseau.

Pour y parvenir, notre recherche inclut les trois étapes suivantes :

Dans la première étape, nous analysons des algorithmes de routage existants et des algorithmes de positionnement du réseau ad hoc.

Dans la deuxième étape, nous concevons et implémentons l'algorithme de routage, qui s'appelle Location-Enhanced On-Demand Routing Algorithm, avec un ensemble de nouvelles stratégies de décision pour le cheminement des paquets dans le réseau.

Dans la troisième étape, nous concevons et mettons en application un ensemble d'expériences de simulation pour évaluer la performance de ce nouvel algorithme et finalement, nous faisons des comparaisons de résultats de simulation avec le protocole d'AODV.

4. REVUE DE LITTÉRATURE

Les problèmes du réseau ad hoc soulève de nombreux défis qui ont alimenté la recherche durant les dernières décennies. Pour résoudre ces problèmes énumérés ci-dessus, les chercheurs ont essayé de concevoir un protocole de routage qui est plus effective, plus efficace, plus sécuritaire et plus conservatif de l'alimentation. En plus, beaucoup de protocoles de routage avaient été développés, comme DSDV, FSR, OLSR, TIENNENT LE PREMIER RÔLE, AODV, DSR, TORA, LAR, etc. Dans les paragraphes suivants nous choisissons quelques protocoles de routage et introduisons leurs fonctionnements et leurs problèmes.

Le protocole optimisé d'état de lien (OLSR) est proposé par l'Institut National De Recherche En Informatique et en Automatique (INRIA) en France [10]. L'amélioration principale d'OLSR est qu'il utilise les Relais Multipoint (MPRs) pour contrôler la transmission de message dans le réseau.

Dans OLSR, les voisins adjacents d'un noeud sont divisés en deux sortes : voisin et MPR. Un MPR est un noeud voisin choisi avec la priorité de livrer des paquets à un voisin de deux sauts. Avec MPRs, l'inondation des paquets dans le réseau est contrôlée et réduite. Il est évident que ce protocole de routage réalise un effet optimal si un plus petit ensemble de MPR est choisi. Par conséquent, nous pouvons dire que l'algorithme de choix de MPR détermine la performance de l'OLSR.

Le concept de MPR est d'abord apparu dans le réseau fixe. Mais Amir Qayyum et al. [21] l'ont appliqué dans le réseau ad hoc et ils ont obtenu une performance optimale. Le MPR limite efficacement le trafic dans un MANET de tel sorte que l'inondation est contrôlée. Ceci indique que la manière la plus normale des paquets traversant le MANET est modifiée par ce protocole de routage. En apprécions la performance du protocole, nous devons également noter que MPRs pourrait également devenir un point critique du MANET. Si un noeud est choisi comme MPR parmi d'autres noeuds, nous pourrions espérer un routage optimisé et efficace. Mais en même temps, le débit des noeuds pourrait conduire le trafic bloquant par ce MPR.

En 1999, Charles E. Perkins et autres [18] a proposé le protocole de cheminement d'AODV. La distinction de ce protocole aux protocoles proactifs est qu'aucune balise de cheminement (qui devrait être envoyé périodiquement dans le réseau globale) n'est exigée. Le protocole d'AODV a trois fonctionnels : Conduisez le sous-programme de question par l'emploi de Route Requête (RQ), le sous programme de réponse d'itinéraire par l'emploi de Route Reply (RR), le sous programme de poignée d'échec (FH).

Au début, le noeud source appelle un sous-programme de RQ pour trouver un chemin au noeud destinataire. Comme décrit ci-dessus, Le RQ inonde des RREQ dans réseau jusqu'à ce que la destination soit trouvée ou l'échec se produit. Chaque noeud intermédiaire reçoit le RREQ et l'expédie à ses voisins. Mais ces noeuds intermédiaires ne tiennent compte pas la direction de l'envoi du RREQ, ils renvoient tout simplement le RREQ qu'ils ont reçu à ses voisins. Seulement le noeud destinataire réponse au RREQ. Une fois que le noeud destinaire reçoit le RREQ, il renvoie un paquet de RREP comprenant l'information de cheminement. Prenant un des chemins du RREQ, RREP pourrait atteindre le noeud source. En conséquence, un chemin bidirectionnel est établi entre la source et la destination.

Une fois que le chemin d'itinéraire est établi, des paquets et des piggybacks sont transmis dans les deux sens. Les noeuds dans un réseau ad hoc se déplacent de temps en temps. Des heures supplémentaires un lien se brise et les échecs se produisent. Une fois qu'un noeud ne pourrait pas détecter son voisin de downlink, il envoie un paquet spécial de réponse, Failure Reply (FR), à son voisin de liaison mont. Par conséquent ce voisin fait suivre ce message de FR jusqu'à la source saut par saut.

Dans la phase d'entretien d'itinéraire, l'itinéraire entre la source et la destination est déjà établi. Une table de routage est créée pour garder l'information de cheminement. Dans AODV, un paquet contient seulement l'information de la destination. Plus de connaissance de cheminement n'a pu être obtenue. Ceci a le but d'éviter avoir un paquet très gros quand l'itinéraire est long, comme celui de DSR.

L'avantage d'AODV en comparaison avec des protocoles classiques de routage comme le vecteur de distance et l'état de lien est qu'il peut considérablement réduire le nombre de messages de cheminement dans le réseau. Pour y parvenir, le protocole AODV emploi une approche réactive. Ceci est nécessaire pour obtenir raisonnable performance du réseau ad hoc quand la topologie change souvent.

Jusqu'à date nous avons étudié plus de trente protocoles de routage du réseau ad hoc, mais les problèmes identifiés ne sont pas encore bien résolus. La recherche récente a proposé d'employer l'information de positions pour optimiser le cheminement. Cette idée semble prometteuse en réduisant la surcharge de trafic généré pour faire la décision de choix d'itinéraire. Les protocoles de cheminement existant basés sur de l'information de position incluent LAR, DREAME, ZHLS, GRILLE, etc.

5. SOLUTION PROPOSÉE

Les protocoles de routage contemporain basés sur des positions dépendent fortement de l'information de position globale, qui utilise habituellement le système de positionnement global (GPS) comme le producteur de base de données de positions.

Mais la praticabilité d'utiliser le GPS dans le réseau ad hoc est en question. Notre recherche indique qu'il y a quatre limitations principales d'employer le GPS dans le réseau ad hoc. D'abord, l'exactitude du GPS courant n'est pas assez précise. En Amérique du nord, le service de position standardisé possède une exactitude de 100 mètres, qui est beaucoup plus loin du besoin de cheminement dans le réseau ad hoc. En second lieu, le GPS exige que l'objet ait accès en vue direct à trois satellites, ceci est défavorable pour le réseau ad hoc qui se déploie dans des secteurs urbains ou en vallées. Troisièmement, il est difficile de déployer le GPS à cause du problème de consommation de puissance. L'installation de fonctionnement d'un terminal GPS dans un ordinateur portatif est impossible. Finalement, la taille physique d'un terminal GPS est trop grande puisqu'il a besoin d'un disque pour recevoir des signaux de satellites

Pour éviter les limitations de la position globale, dans ce mémoire nous proposons de remplacer la position globale par la position locale pour faciliter le cheminement dans le réseau ad hoc. En fait, l'information de la position locale est plus intuitive que celle de la position globale. En cas de la position global, pour vérifier si deux nœuds sont voisins ou non, il faut prendre deux positions globales et calculer avec certaines équations. Mais en cas de la position locale, si la distance d'un noeud à un autre nœud est donnée, on pourrait immédiatement déterminer s'ils sont des voisins.

Une antenne intelligente est un ensemble rangé d'éléments d'antenne reliés à un processeur de signal numérique, dans lequel certains algorithmes sont déployés pour traiter et filtrer des signaux reçus, afin d'améliorer la qualité de communication. Ainsi, l'antenne intelligente peut localiser les noeuds mobiles dans sa gamme. Nous proposons d'utiliser l'antenne intelligente pour obtenir l'information de position dans ce travail.

Pour profiter d'information de position locale, dans ce travail, nous présentons à un nouvel algorithme de routage du réseau ad hoc, le *Location-Enhanced, On-Demand Routing* (LOR), pour démontrer comment la position locale pourrait assister le routage ad hoc. Le but principal du LOR est d'éliminer de la surcharge de trafic autant que possible dans le réseau ad hoc. Pour y parvenir, l'algorithme LOR utilise l'information de la position locale pour faciliter la décision d'itinéraire, alors un ensemble de nouveaux mécanismes est développer à la prise d'information de position, et seulement des participants au long de la route sont impliqués afin de synchroniser l'information de position. Étant un protocole réactif, le protocole LOR est basé sur le protocole de routage sur demande (AODV) qui est aussi un protocole du vecteur de distance [18].

La table suivante compare les différents comportements pas à pas entre l'AODV et le LOR.

Étape	AODV	LOR
RREQ	• Inondation	• Inondation, sans connaissance de destination. • Inondation restreinte, avec la connaissance. • Synchronisation de la coordonnée du réseau
RREP	• Recevez et expédiez RREP.	• Recevez et expédiez RREP • Synchronisez la coordonnée du réseau
RE	• Sur le premier RREP	• Calculez *les degrés de connectivité* • Choisissez un itinéraire plus stable plutôt que fragile

RM	• Périodiquement beacon • Envoyez RERR au cas d'échec itinéraire • Re-inondez sur RERR	• Optimisez dynamiquement l'itinéraire par Route Reduce • Surveillez si l'itinéraire est actif • Envoi de Beacon selon le statut de connexion • Réparation locale • Re-inondez si réparation locale non réussite.

6. MODÈLE DE SIMULATION

Un modèle de mobilité est conçu pour résoudre le problème d'imiter tous les mouvements réels du réseau ad hoc dans la vraie vie. Pour établir un tel modèle, la manière la plus franche est de tracer les mouvements des stations dans un vrai réseau ad hoc et puis de soustraire le pattern de mouvement. De cette façon, on doit observer pendant longtemps les mouvements d'un grand nombre de stations, pour obtenir l'information utile. En plus, le pattern de mobilité est clairement dépendent de l'application. Évidemment, un tel modèle a des limitations, parce que le pattern de mouvement du réseau ad hoc change de temps en temps. Par exemple, la mobilité des véhicules dans une ville serait de haute vitesse, mais limitée par la grille constituée des routes, tandis que les dispositifs sonde dispersés dans le ciel n'auraient probablement aucune restriction environnante d'obstacle dans leurs mouvements. Au lieu de tracer les vrais mouvements du réseau, T. Camp et al. [32] ont proposé le modèle synthétique pour imiter les modèles de mobilité réels aussi semblable comme possible. Ce modèle définit d'abord un modèle de la mobilité des entités, et applique ensuite différents modèles de mobilité de groupe aux entités dans les groupes. Ce modèle synthétique sans aucun doute est un meilleur choix d'imiter toutes les sortes de pattern de mobilité du réseau ad hoc à modeler.

Le modèle de mobilité de promenade aléatoire (Random Walk) a été présenté dans [35]. Il a été développé pour imiter les mouvements erratiques des entités physiques. Ce modèle de mobilité est basé sur plusieurs hypothèses ci-dessous :

- Les intervalles consécutifs de temps du mouvement mènent à un autre pour chaque noeud indépendamment.
- Le mouvement est limité, car chaque nœud doit se déplacer suivant une ligne.
- Chaque noeud se déplace à une vitesse seulement à tout moment, qui signifie qu'elle n'a nulle accélération.
- Les mouvements se produisent seulement soit pendant des intervalles discrets de temps, soit une distance fixé est traversée.

Dans ce modèle, la direction, mesurée en degrés et la vitesse du mouvement est choisie aléatoirement à partie des gammes prédéfinies. Si un noeud atteint la frontière de la région graphique représentant le réseau, il devrait retourner en arrière.

La direction aléatoire est réalisée en choisissant aléatoirement une direction, mesurée en degrés, plutôt qu'une position dans le secteur. La direction rencontre les frontières du secteur à un point spécifique. Ce point est choisi comme la destination du noeud. La vitesse est choisie d'une façon uniformément aléatoire, et le mode allant à sa destination est spécifié avec une vitesse donnée au début. Une fois qu'il atteint la destination, il se repose pendant un temps de pause prédéterminé, et puis choisit une nouvelle direction.

Le modèle de simulation est établi en langue C++ pour évaluer la performance de l'algorithme LOR. La description détaillée de ce modèle est donnée, et des paramètres d'entrée et de sortie sont également définis et assignés avec des valeurs appropriées.

7. RÉSULTATS D'EXPÉRIENCE ET ANALYSE DE LA PERFORMANCE

Dans cette expérience, le débit de réseau est un pourcentage de tous les messages livrés sur tous les messages arrivés au réseau. L'algorithme LOR possède une meilleure performance que le protocole AODV. Le LOR a une tendance de garder son débit autour de 80% tandis que l'AODV autour 65%. Ici 100% signifie que toutes les données de 100Mb sont terminées leurs transmissions dans une période moyenne de 100,000 itérations.

Le programme rassemble le nombre global de paquets de contrôle générés et le nombre global de paquets générés durant la simulation. Le taux de paquets de contrôle sur tous les paquets générés contribue à la surcharge de trafic de signalisation du réseau ad hoc.

Avec les résultats de la simulation, on peut conclure que l'algorithme LOR a une surcharge strictement plus petite que le protocole AODV peu après la simulation déclenchée. Le LOR maintient au niveau de 50% tandis que l'AODV augmente et atteint 60% à la fin de la 100,000th itération.

Le délai moyen de bout en bout est un autre index important dans l'évaluation des performances. Les deux algorithmes possèdent simplement le même délai sur cet index. Le délai moyen est beaucoup plus grand, autour de 11.5 secondes sur 1Mb.

Le rapport de puissance d'énergie mesure la consommation de la puissance en watts par message d'un Kb. Supposez que il faille consommer 1 watt de la puissance de batterie pour transmettre au maximum un message de 1Kb. Le LOR a un rapport de puissance d'énergie beaucoup plus inférieur que l'algorithme d'AODV. Le LOR consomme à peu près de 11.5 watts de puissance pour transmettre un message de 1Kb, alors que l'AODV consomme 13.5 watts. Le LOR démontre un gain de l'économie de puissance environ de 15% dans cette expérience.

8. CONCLUSIONS ET TRAVAUX FUTURS

Ce travail présente un algorithme de routage du réseau ad hoc basé sur un nouvel mécanisme de localisation, Location-Enhanced On-demand Routing (LOR). L'idée de cet algorithme LOR est originale parmi des algorithmes de routage contemporain basés sur de l'information de la position car nous proposons d'employer la position locale au lieu de l'information globale. Déploie du mécanisme de position local mène à une série de changements à propos du calcul de coordonnés, la synchronisation de l'information de position, et la décision du choix d'itinéraire. Ce nouvel algorithme démontre une performance prometteuse en réduisant de la surcharge de trafic de la signalisation du réseau ad hoc.

Dans ce travail, nous supposons que le mécanisme de positionnement est assez précis pour accomplir nos besoins de localisation. Mais l'installation des antennes intelligentes a des limitations. L'impact de l'exactitude sur place n'est pas étudié en détail. C'est une limitation importante de notre recherche. La deuxième limitation est que nous avons ignoré la surcharge de calcul produit par l'algorithme de positionnement GPS-free qui est un algorithme complexe et génère la surcharge de calcul dans un terminal mobile.

Le LOR hérite de son prototype AODV, plusieurs de ces propriétés, telles que la liberté de boucle (Loop Freedom), opération distribuée, et multicast. En profitant de l'information de localisation, le LOR également a amélioré l'aspect de conservation de puissance et de l'évolubilité. Nous notons que le LOR, étant un algorithme basé sur position locale, est capable de profiter d'information de position pour raffiner dynamiquement la décision de choix d'itinéraire, et aussi supporte le cheminement de message de QoS. Ceux-ci sont laissés comme nos futurs objectifs de recherches.

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2G	Second Generation Cellular System
ACK	Acknowledgement package
AoA	Angle of Arrival
AODV	Ad-hoc On-demand Distance Vector
APS	Ad hoc Positioning System
BRP	Broadcast Resolution Protocol
BS	Base Station
CPU	Central Processor Unit
DARPA	Defense Advanced Research Projects Agency
DID	Destination node identifier
DoC	Degree of Connectivity
DoD	Department of Defense
DREAM	Distance Routing Effect Algorithm for Mobility
DSDV	Destination Sequenced Distance Vector
DSR	Dynamic Source Routing
DV	Distance Vector
FH	Failure Handle Subroutine
FR	Failure Replay package
FSR	Fisheye State Routing
GPS	Global Positioning System
GRID	Grid Routing
GSM	Global System for Mobile Communication
IARP	Intra-zone Routing Protocol
IERP	Inter-zone Routing Protocol
INRIA	Institut National de Recherche en Informatique et Automatique

Kb	Kilobit
Km	Kilometer
Km^2	Square Kilometer
LAR	Location-Aided Routing
LCS	Local Coordinate System
LOR	Location-enhanced On-demand Routing
LPS	Local Positioning System
LSA	Link State Advertisement
MANET	Mobile Ad Hoc Network
Mb	Megabit
Mbps	Megabits per secons
MPR	Multipoint Relay
ms	Millisecond
m/s	meter per second
OLSR	Optimized Link State Routing
QoS	Quality of Service
PCS	Personal Communication System
RE	Route Establishment
RERR	Route Error package
RF	Radio Frequency
RM	Route Maintenance
RQ	Route Query subroutine
RR	Route Reply subroutine
RREP	Route Reply
RREQ	Route Request
RS	Route Searching
SID	Source node identifier
SEQ	Sequence number

SS7	System Signaling 7
STAR	Source-tree Adaptive Routing
TDoA	Time Difference of Arrival
TORA	Temporally-Ordered Routing Algorithm
ZHLS	Zone-based Hierarchical Link State Routing
ZRP	Zone Routing Protocol

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Chapter 1
Introduction

Networks without cable connections are called wireless networks. In such kind of networks, radio waves take the place of cables in wire-lined networks to act as the carrier of signals. This characteristic of wireless network enables the nodes to communicate while moving within the range of radio coverage. Because the wireless networks provide service of mobility to the subscribers, they are also called mobile networks or mobile wireless networks.

Currently, the most prevalent wireless networks are infrastructure mobile wireless networks. In an infrastructure network, some fixed nodes bridge the communications among mobile terminals. These fixed points are called Base Stations (BSs). While a mobile terminal is roaming in a wireless network, it sometimes traverses the border between two BSs; hence its access point to the network is changed accordingly. We call this a handoff. The handoff enables mobile terminals to subscribe service of mobility network-wide. In an infrastructure network, Base Stations are the backbone nodes which define the framework. Hence the topology of an infrastructure network is still fixed. A good example of infrastructure wireless networks is the cellular network. Let's imagine if a continental wide infrastructure mobile network is built, all subscribers will be free to access network resources at any time and any where. But unfortunately, this solution is not commercially feasible. In areas where the population is sparse, such as Arctic area, or mountain areas, we could hardly see radio base stations. In the real world, there are occasions when networks need to be deployed in such areas. Tactical networks need to be deployed in battle fields where existing radio stations are destroyed. A Search-and-Rescuer team usually forms a temporary network in mountain areas avalanched. A solution to the above situations is to build a special temporary wireless network to fulfill the needs. In such a network, nodes are mobile. The nodes act as terminals as well as backbones. A significant characteristic of this type of network is that it even does not have a fixed topology. We call these networks the ad hoc networks.

1.1 Mobile Ad Hoc Networks

Ad hoc is a Latin phrase which means *for this [purpose]*. This well explains how the network is named. It is a temporary network that is composed for a special reason and dismissed after the mission is completed. In 1970's, the Defense Advanced Research Projects Agency (DARPA), which the is the central research and development organization for the Department of Defense (DoD) of the United States, initiated a tactical project to build a special mobile wireless network being used in the battle field, where no preinstalled radio base station could exist. This network is now known as the earliest mobile ad hoc network (MANET).

Ad hoc networks distinguish themselves significantly from infrastructure networks in the way of connection. An ad hoc network consists of a group of mobile nodes. Between every two nodes, the communication is carried out through radio. When the target node of the communication is out of range, the initiator of the communication tries to locate the target node by multi-hop routing. All nodes in the network are backbone nodes, which mean they act as routers as well as subscribers simultaneously. But because of the movement of the nodes, routing topology becomes uncertain in the network. It is possible that the route between two communicating nodes changes several times in a short dialog. Ad hoc networks are always formed temporarily for some specific reasons, such as battle, search and rescuer, or meeting and conventions. In commercial occasions, stationary or semi-mobile nodes could also be seen in ad hoc networks functioning as Internet gateways.

1.2 Problem Addressing

One of the important of ad hoc routing protocol is that the performance is suffering from control overhead. Control overhead is the control messages generated over the network routing management. Two of the ad hoc network characteristics contribute to it –

dynamic topology and multi-hop routing. Dynamic topology is a born-to-be nature of the ad hoc network. Multi-hop routing means when a node want to communicate with another remote node, it needs several intermediate nodes to relay messages, contrast to reach it directly. Limited by radio channel bandwidth, power supply, and other factors, multi-hop routing is inevitable in most cases. Multi-hop routing implies that a route usually involves several nodes, while dynamic topology implies the route might be changed during the communication. Thus, nodes may lose connection to their audience overtime and control packages have to be sent to resume interrupted connections. Control overhead may lead to the following severe problems:

- badly decreasing the quality of service of the ad hoc network.
- long average waiting time for data package transmission,
- high ratio of data lost,
- poor network throughput,
- and no guarantee of end to end communication,

which are not acceptable but happened in ad hoc networks.

To resolve the above enumerated problems, scientists endeavor in finding more effective, efficient, secure, and power conservative routing protocols. Many protocols had been developed, such as DSDV, FSR, OLSR, STAR, AODV, DSR, TORA, LAR, etc. So far we have known more than thirty ad hoc network routing protocols, but we can hardly say that the problems identified are well resolved. Recent research proposed to use location information to optimize routing. This idea sounds promising in reducing the overhead generated on route decision. Existing location based ad hoc routing protocols include LAR, DREAM, ZHLS, GRID, etc. Contemporary location based routing protocols highly depend on global position information, which usually employs the Global Positioning System (GPS) as the location information provider. But the synchronization of global information leads to a dilemma – it also raises overheads.

1.3 Research Objective

Global position based routing algorithms need to synchronize network topology periodically. As a network of a hundred nodes, if there are ten nodes participant in route decision, then the synchronization overheads of the other ninety nodes are unnecessary. As global positioning heavily depends on GPS services, problems are also raised, such as the cost, the power consumption, the availability of service, the feasibility of equipping GPS terminals on small physical nodes, etc.

More recently, new technologies and algorithms are also introduced in resolving those traditional problems. Dragos Niculescu et al [16] pointed out that smart antennas could be used in local positioning, and proposed a series of algorithms of local positioning, such as LPS [15] and APS [13]. These algorithms disclosed that a node could detect the relative position of its direct neighbor with the aid of smart antenna to help routing.

Our research endeavors to propose a local position based routing protocol as a solution to the addressed problems. The conceived new ad-hoc routing protocol should posses the following properties:

- Based on local position,
- GPS independent,
- Synchronize position information only on-demand,
- Reduce control overhead,
- Power conservation, and
- Improve network performance.

To fulfill the goal, our research includes the following three steps:

- In the first step, we analysis existing routing algorithms and ad hoc positioning algorithms.
- In the second step, we conceive and implement the Location-Enhanced On-demand Routing algorithm with a set of new routing decision

strategies.

- In the third step, we design and implement a set of simulation experiments to evaluate the performance of the novel algorithm based on comparisons with the AODV protocol.

1.4 Work Outline

The work is structured as following: In Chapter 1, the basic concepts of mobile wireless network and ad-hoc network is presented. Based on the problem addressing of ad hoc network routing, we propose a novel routing protocol as a solution. In Chapter 2, detailed studies on contemporary ad hoc routing protocols and ad hoc positioning algorithms. In Chapter 3, we present the solution to problems addressed in Chapter 1 – Location-enhanced On-demand Routing protocol. In Chapter 4, the performance of the new protocol is analyzed based on the results of simulation. In Chapter 5, conclusions are drawn. Future work is defined as the direction of our next step research.

Chapter 2
Literature Review

This chapter first reviews some typical and traditional routing protocols in mobile ad-hoc networks. Then location based ad hoc routing is presented as a direction of development of ad hoc routing technologies. Following the introduction to routing protocols, some ad hoc positioning algorithms are introduced.

2.1 Review of Ad-Hoc Routing Protocols

As mentioned in Chapter 1, ad hoc routing protocols are divided into two major categories – proactive protocols and reactive protocols.

A proactive protocol usually actively maintains routing information in the network. Each node keeps a routing table to every other node and refreshes its routing tables timely. The advantage of the proactive routing protocol is quite intuitive – once a node has a message to send, it knows who the next hop to the destination node is immediately by consulting its routing table. When the ad hoc network is in low mobility, a proactive protocol functions perfectly. But it is very difficult for such a protocol to keep all routing information valid in a rapidly changing ad hoc network.

A reactive protocol does not know the exact path in the network before a package is sent. By sending a special package traversing over the network, a node finds its path to the destination and forwards a message to it. Control overheads in a reactive protocol are easily seen – almost all nodes in the network are involved in route searching, yet only some nodes are desired recipients. But in practice, the reactive protocols also show very good performance in many circumstances. For example, in a rapidly moving ad hoc network, using of a reactive protocol could be a wiser choice. For better understanding the characteristics of ad hoc routing protocols, next let us study some of the typical ad hoc routing protocols in details.

Following we will study the four typical ad-hoc routing protocols introduced above, namely OLSR [1,2,9,10], AODV [1,8,18], and ZRP [1,7,8,24,28], in details.

2.1.1 Optimized Link State Routing Protocol (OLSR)

Before Optimized Link State Routing Protocol is introduced, it is necessary to have a quick review of a conventional link state protocol. A link state protocol requires each node in a network to maintain routing information of the network. A node forwards the package to the next hop to the destination according to the routing table. Once a node's routing table is changed, it floods link states advertisement (LSA) to inform the change.

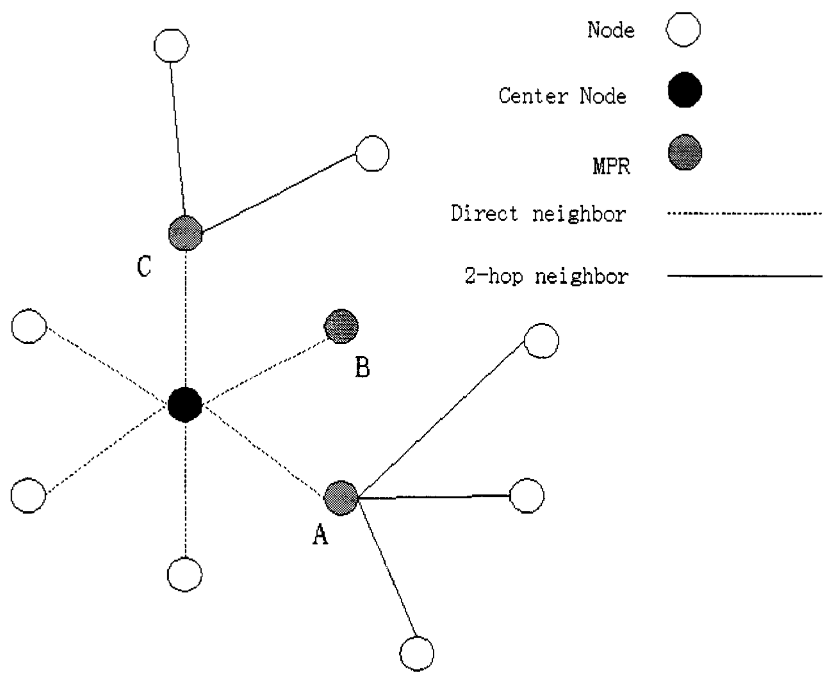


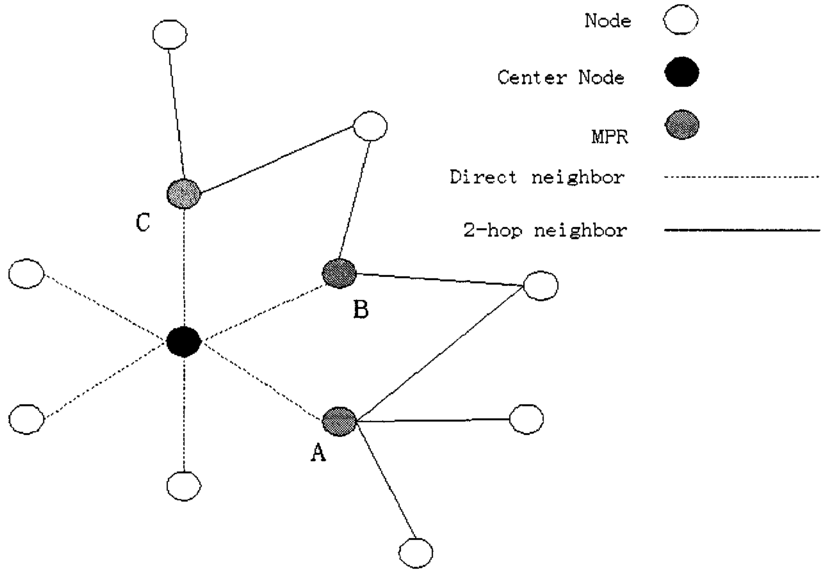
Figure 2-1 Multipoint Relays

The Optimized Link State Protocol [10] is first proposed by Institut National de Recherche en Informatique et en Automatique (INRIA), France. The key improvement of OLSR is that it uses Multipoint Relays (MPRs) to control message transmission in the network.

In OLSR algorithm, a node's direct neighbor is categorized to be either an ordinary neighbor or a MPR. A MPR is a selected direct neighbor node that is given the priority to deliver packets to two hop neighbors, see Figure 2-1. With MPRs, the flooding of packets in the network is controlled and reduced. It is obvious that the routing protocol achieves an optimal effect if a smaller MPR set is selected. Hence, the selection of MPRs decides the performance of the OLSR.

Amir Qayum et al. [21] have proposed to select the MPR set with a heuristic algorithm. Three sets are predefined as *MPR*, *N*, and N_2, where *R* stands for the collections of multipoint relay, *N* for neighbors, and N_2 for two hop neighbors respectively. The algorithm surveys all elements in *N*, ranks the nodes by the number of two hop neighbors that it connects in N_2, and picks up the node of the highest rank into *MPR*. As shown in Figure 2-2, the algorithm terminates when all nodes in N_2 are connected by *MPRs*. With *MPRs* picked out, the OLSR functions like an LSR protocol. It passes a package from the source to the destination by consulting the link state table.

The concept of MPR is first appeared in fixed network. But Amir Qayyum et al. [21] have creatively applied it in the ad hoc networks and achieved an optimal performance. The MPR effectively limits the traffic in a MANET. The flooding is then controlled. This shows that the protocol changes the most natural way the packages traverse in the MANET. As we appreciate the performance the protocol achieves, we also have to notice that MPRs also could become the bottle neck of the MANET. If a node is selected as the MPR of many other nodes, we could expect an optimized routing effective. But at the same time, the throughput of the nodes might block the traffic.



Round 1 : A connects to 3 2-hop neighbors
B connects to 2 2-hop neighbors
C conneccts to 2 2-hop neighbors
A is selected a MPR

Round 2: B connects to 1 2-hop neighbor
C connects to 2 2-hop neighbors
C is selected a MPR
No more 2-hop neighbors, algorithm terminates!

Figure 2-2 Heuristic Algorithm

2.1.2 Ad-Hoc On-demand Distance Vector Routing (AODV)

In 1999, Charles E. Perkins et al [18] proposed the AODV routing algorithm. The distinction of this protocol to proactive protocols is that no periodic beacon is required. Initially, an ad hoc network is 'tranquil'. Once a node initiates a call, the algorithm is invoked to search, to build, and to maintain a valid route. The AODV protocol has three functional subroutines: Route Query subroutine (RQ), Route Reply subroutine (RR), Failure Handle subroutine (FH).

Route Query Subroutine

Route Query subroutine is carried out by a non-destination node, namely the source node or any intermediate nodes, to find paths to the destination node. Once a non-destination node receives a *Route Request* package (RREQ), RQ is invoked to handle. RQ compares the *source node identifier* (SID) and the *sequence number* (SEQ) of the received *RREQ*, then decides if the *RREQ* will be forwarded or discard. The *SID* of the *RREQ* will be increased by 1 before it is retransmitted.

Upon receiving a *RREQ*, destination node initiates a *Route Reply* (RREP) package as an answer. Different from *RREQ*, the *RREP* is unicasted, which means a received *RREP* is sent only to its next hop neighbor toward the source node.

Route Maintaining Subroutine

Once a route path is established, packages and piggy backs are delivered back and forth. But there exists some time interval that no package is transferred between two nodes. If the time interval exceeds a limit, namely hello-interval, Route Maintaining subroutine launches. By then, the two nodes will send each other a *beacon* message, or *hello* message. If the downlink nodes do not reply the *beacon*, uplink nodes will invoke Failure Handle subroutine.

Failure Handle Subroutine

Nodes in a MANET move from time to time. Overtime a link breaks and failures occur. Once a node could not detect his downlink neighbor any longer, it sends a special reply package, Failure Reply (FR), to its uplink neighbor. The neighbor consequently forwards the FR to the source hop by hop.

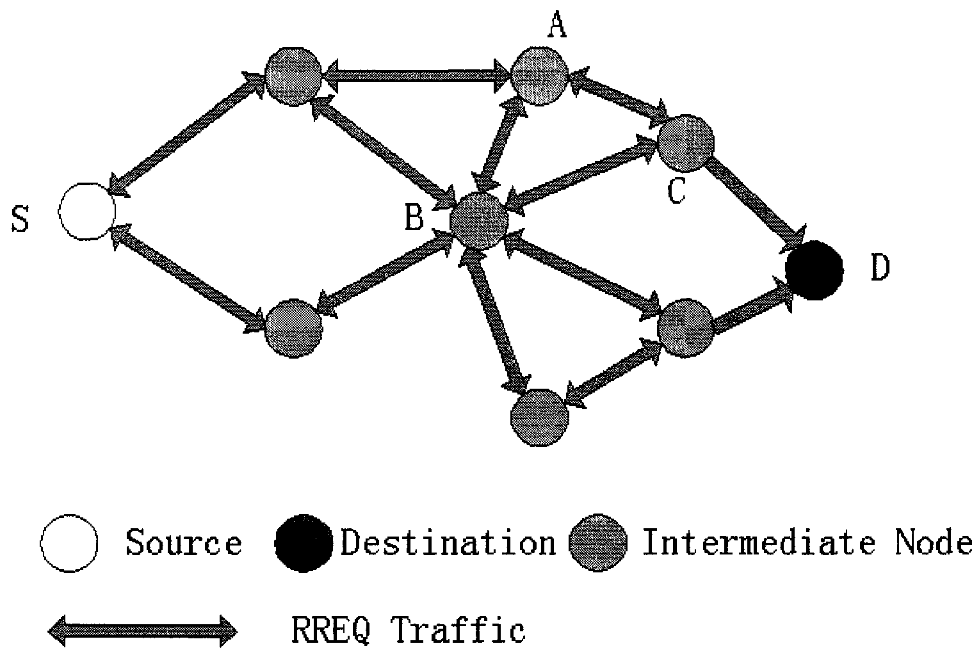


Figure 2-3 Route Request Flooding

Path Construction phase

At the beginning, the source node calls a *RQ* subroutine to find the path to the destination node. As described above, *RQ* floods *RREQ* over the network till the destination is found or failure occurs. As Figure 2-3 indicates, each intermediate node receives and forwards received *RREQ* to its neighbors.

From Figure 2-3 we can see that the *RREQ* is really flooding. The intermediate nodes do not care the direction but simply resend the *RREQ* they heard. Only the destination node is absorbing to the *RREQ*.

Once the destination node receives the *RREQ*, it sends back a *RREP* package including routing information. Along one of the coming paths of *RREQ*, *RREP* reaches source node, see Figure 2-4. Hence, a bidirectional path is established between the source and the destination.

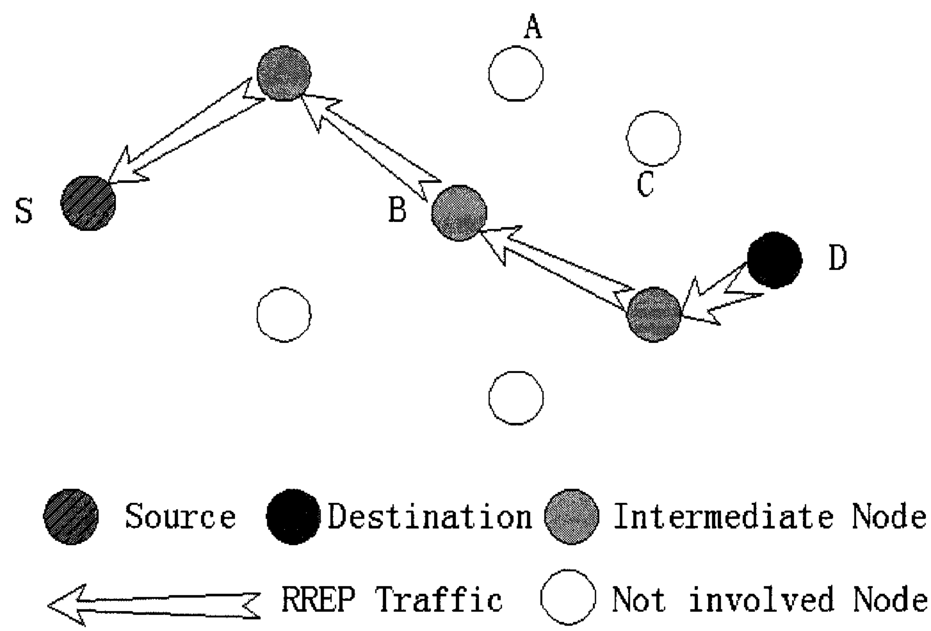


Figure 2-4 Route Reply

However, loop may occur during the flooding [4]. As demonstrated in Figure 2-3, node *A* sends a *RREQ* to node *B*; node *B* forwards it to node *C*; node *C* transmits it to node *A*, and so on. A loop will destroy the MANET. AODV provides a loop free mechanism to reduce loops. In this figure, *C* and *B* receive the same *RREQ* from *A*. When *B* and *C* receive it from each other, they compare the *SID* and *SEQ* of the *RREQ* to their previous heard one. They find the two *RREQ* are identical and discard it without response to it.

Route Maintenance Phase

In this phase, the route between the source and the destination is already established. A routing table is created to keep the routing information. In AODV, the package only contains the destination. No more routing knowledge could be obtained. This is to avoid a very fat package when the route is long, as it is in DSR. A routing table usually contains the following items:

- Destination
- Next Hop

- Number of hops
- Sequence number for the destination
- Active neighbors for this route
- Expiration time for the route table entry

RM subroutine and FH subroutine are employed in this phase to ensure the route active. By setting a timer, a node frequently beacons its neighbor to make sure it is still active. This beacon message is only a one-hop message; hence it will not flood over the network.

Route Delete Phase

Usually this phase is not described as an independent phase, because the task is relatively simple. After the dialog terminates, the source does not send a message to inform all the nodes in the forward path to delete the according routing table. When the network traffic is busy, keeping of the old path information facilitates future routing to some extent. But this does not mean that the information of an expired route should be reserved life long. Nodes are moving, and routes are changing soon. A timer is set to alert if the route is long time no use. In that case, the routing table is deleted.

The advantage with AODV compared to classical routing protocols like distance vector and link-state is that AODV has greatly reduced the number of routing messages in the network. AODV achieves this by using a reactive approach. This is necessary in an ad-hoc network to get reasonably performance when the topology is changing often.

2.1.3 Zone Routing Protocol (ZRP)

Zone Routing Protocol is considered as a hierarchical protocol [1]. It groups nodes in a MANET into different zones. If a node wants to communicate with another, it first searches if the counterpart is in the same zone of itself. Nodes in different zones communicate thought gateway nodes. Hence zones form the first tire, and gateway nodes form the second tire of the hierarchy. In a zone, proactive protocols are used to maintain routing information; among the zones, reactive protocols are utilized to work out a route on demand. Thus, the ZRP protocol is also categorized as a hybrid protocol.

The first problem in ZRP is how to define a routing zone. Haas et al in [7,8] have proposed to define a routing zone by hop. "More precisely, a node's routing zone is defined as a collection of nodes whose minimum distance in hops from the node in question is no greater than a parameter referred to as the zone radius. Note that each node maintains its own routing zone." [8]. From Figure-2-5 we see, if the hop number is set to 2, then node *B*, *C*, *D*, and *E* are in *A*'s zone.

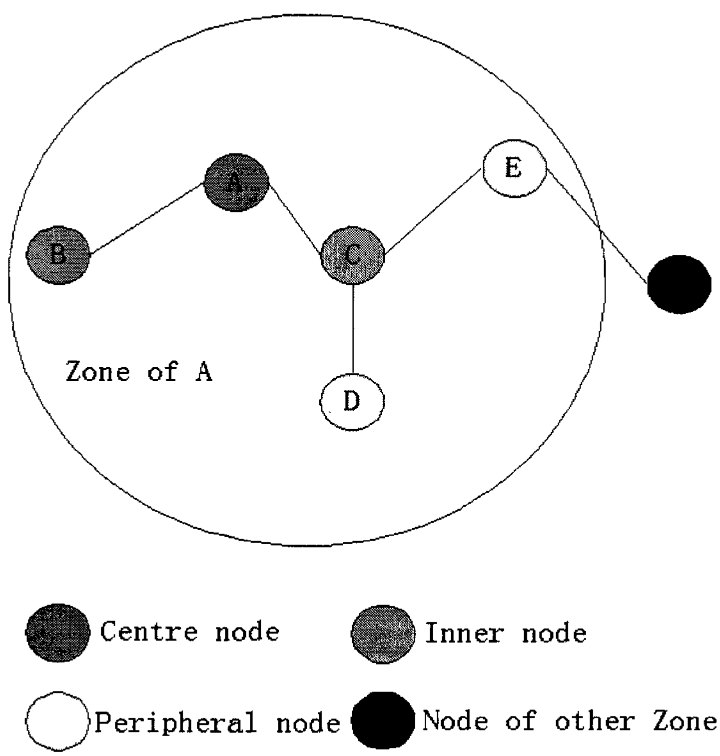


Figure 2-5 Zone of Node *A*

In a zone, at least one node is designated as the gateway. Usually a gateway node is selected from peripheral nodes. See Figure 2-5, node *D* and node *E* are peripheral nodes and E is selected as the gateway.

In a routing zone, the Intra-zone Routing Protocol (IARP) [8] functions to deliver packages in the range of the zone. The protocol is not defined and can include any of proactive protocols. One rule has to be followed is that if in a zone a routing protocol is used, every other node in the zone also has to adapt the same protocol. As zones overlap, it is predictable that a node could have employed multiple protocols to fit the need of different zones.

The Inter-zone Routing Protocol (IERP) [8] refers to the reactive protocol that is used for finding routes between different routing zones. Different IARP, IERP is restricted to the Broadcast Resolution Protocol (BRP) only. The way the BRP functioning is somewhat distinct from an ordinary reactive protocol. It only forward a route request package (RREQ) to its peripheral nodes. Once a peripheral node receives a RREQ, all nodes in its zone are marked as 'covered'. The peripheral node forwards the RREQ only to its uncovered peripheral neighbors to avoid loop. In the end, the destination is found and a route reply package (RREP) is send back.

ZRP is a very interesting protocol. Its operation can be adjusted according to the current network operational conditions (e.g. change the routing zone diameter). However, this is not done dynamically, but instead it is suggested that this zone radius should be set by the administration of the network and with a default value by the manufacturer. The performance of ZRP protocol is highly depending on this condition.

As a hybrid scheme, the ZRP protocol takes the advantages from both reactive and proactive schemes. Inside a routing zone, routes can be found very fast; while outside the zone, routes can be found by efficiently querying selected nodes in the network. However, one problem is that the proactive intra-zone routing protocol is not specified. Using of different intra-zone routing protocols implies that several protocols have to be supported. This is not a good idea when dealing with thin clients. It is better to use same intra-zone routing protocol in the entire network.

2.2 Location Based Routing in Ad Hoc Networks

No matter the proactive routing, the reactive routing, or the hybrid routing scheme in ad hoc networks, periodically beaconing to explore neighbors is inevitable. Especially for the proactive protocols, beacons keep the protocols functioning. But it is also very resource consuming to beacon neighbors timely. If a node could acknowledge its neighbor's absolute or relative position in the network, many control messages could be saved. Location based routing protocols are mostly proposed from this point of view.

2.2.1 Location-Aided Routing Protocol (LAR)

With the constant moving of nodes in an ad hoc network, the distribution of nodes changes from time to time. Most of the ad hoc routing protocols use the flooding algorithm to discover paths. But the tradeoff is the waste of a large portion of radio bandwidth. If the positions of nodes are known, the waste then could be limited in an acceptable range. Yong-Bae Ko et al. in [11] proposed the Location-Aided Routing, which employs the Global Positioning System (GPS) to facilitate the routing in the ad hoc network.

The protocol assumes that the ad hoc network deploys in a flat area and each node knows its global position from the equipped GPS terminal. Overtime, the source node S need to communicate with the destination node D but failed due to the broken of the previous route. Same as in all other protocols, the Source initiate a flood to find out a new path. The difference is the flood is restricted in a desired area only.

After S finished talking with D at time t_0, it wants another communication with D at time t_1. The time interval $\Delta t = t_0 - t_1$. S knows its position at time t_1 is $P_S(x_1, y_1)$, but the position of D, $P_S(x_1, y_1)$, is unknown to S. It is assumed that the maximum speed of nodes in the MANET is given as v. Then we can deduce that D must be in a circular area C (expected zone) with the original point $O_D(x_0,y_0)$ and radius $r = v{\cdot}\Delta t$. Now the two cut of S to C forms a routing area, say Request Zone, see Figure 2-6.

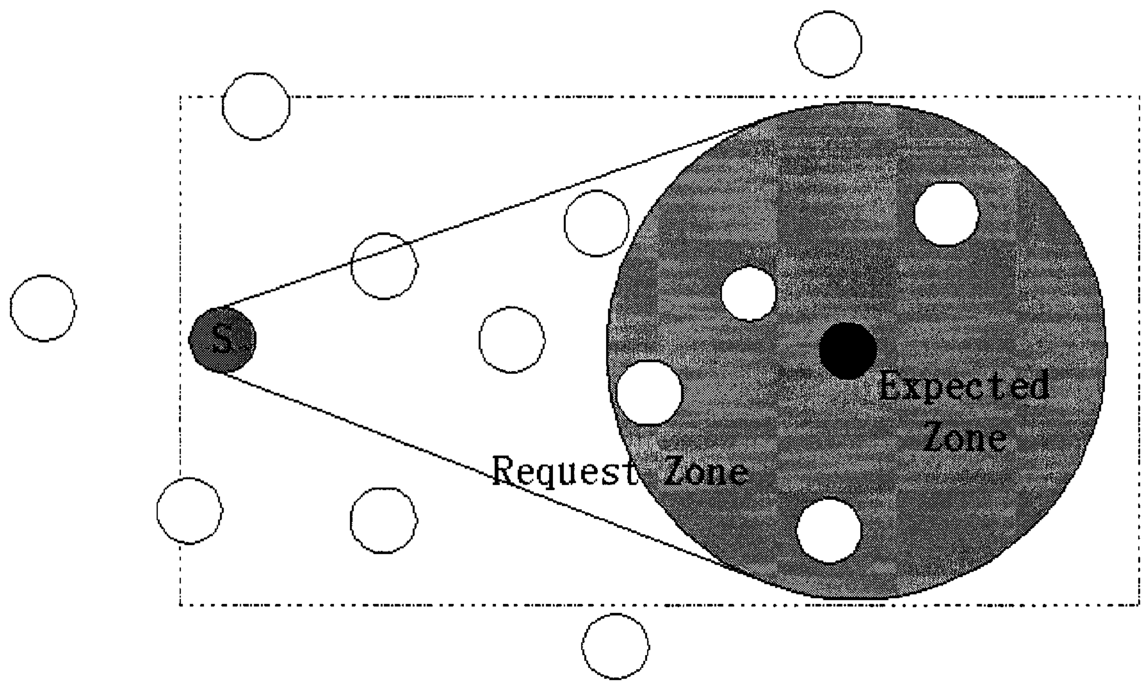


Figure 2-6 Expected Zone and Request Zone

Flooding restricted in the Request Zone reduces overhead. Once a route request is initiated, nodes calculate if they are in the Request Zone or not. Only nodes that are in the zone forward RREQ to their next hop neighbors, others discard the message.

In practice, the Request Zone is always set to a rectangular that initiates with $P_S(x, y)$ and includes the entire expected zone C, as shown in Figure 2-6. It is much easier for a node to calculate if it belongs to the Request Zone.

LAR is a location-based protocol. With the help of GPS, nodes are self-positioning capable. The location information helps to restrict the flood in a smaller range than topology-based routing protocol. This is a significant improvement in the ad hoc routing, because the flooding is believed most resources consuming but inevitable.

But to apply GPS in the mobile ad hoc networks is expensive. Sometimes it looks not economically and electrically affordable due to the service charge and power consumption. As another aspect, the GPS works well in the field but becomes ineffective in buildings because of signal absorption. Thus global-positioned protocols are limited in metropolitan area. Although ad hoc networks are first applied in tactical use, they tend to be well adapted in commercial use.

2.3 Ad-hoc Positioning Algorithms

Existing ad hoc location based routing protocols, such as LAR [1,11] and DREAM [1,12], are basically GPS based. They need position information provided by a third party application – the Global Positioning Service. This, as discussed above, decreases the usability of location based protocols. As another matter of fact, mobile node itself is capable of positioning or self-positioning to some extent. The device a node using to send and receive radio signals – the antenna or antenna array, also called the RADAR system, is widely used in the field of positioning. Obviously, with the aid of certain algorithms, an ad hoc network is able to position its nodes independently.

Early positioning applications were used to locate a submarine in the sea with the sonar system or to test the speed of a vehicle on the highway with the radar system. The second generation cellular system (2G, or GSM) extend the positioning algorithms to locate mobile service subscribers. In GSM networks, Base Stations locate a mobile user with radio waves. Naturally, scientists think of replacing the base stations in GSM with mobile nodes in the ad hoc. Many algorithms are proposed, but due to the limitation of pages, here we review only Ad Hoc Positioning System (APS) and Local Coordinate System (LCS), which are most instructive to our research.

2.3.1 A GPS free positioning algorithm

Most of ad hoc positioning algorithms require global position information from the GPS. Some of them even could not function without GPS support. But it is clear that not all of the MANETs have access to GPS service. A GPS free positioning algorithm – Local Coordinate System (LCS) is proposed by Srdan Capkun et al. in [3] in 2001. This algorithm endeavors in building every node's local coordinate system.

Establishment of Local Coordinate

Begin with the node itself as the center of its local coordinate, a node sends beacon messages to its immediate neighbors to draw a partial map of the network. In this stage the algorithm has three tasks:

- detect all one hop neighbors of each node in the network,
- measure the distances to all one-hop neighbors,
- forward the distance information to every other one-hop neighbors.

After the above three steps, a node knows its one-hop neighbors and two hop-neighbors as well. A node, say node *O*, chooses two special nodes arbitrarily to build up its coordinate. The two nodes, namely *H* and *T*, must be each other's immediate neighbor as a requirement of the algorithm.

Node *O* is the origin of its local coordinate. *H* is put on the horizontal axis of the coordinate with the distance *D(OH)* to *O*. See Figure 2-6. With *T* properly filled into the coordinate, the three points forms a triangle as following: *O(0, 0)*, *H(D(OH), 0)*, and *T(D(OT)Cosθ, D(OT)Sinθ)*, where θ is the angle $\measuredangle(HOT)$. The degree of θ is derived from the triangle law:

$$\theta = arccos\frac{D(OH)^2 + D(OT)^2 - D(HT)^2}{2D(OH)D(OT)} \quad (2.1)$$

Furthermore, Srdan Capkun et al in [3] indicate how to calculate the other nodes' position based on the *HOT* triangle.

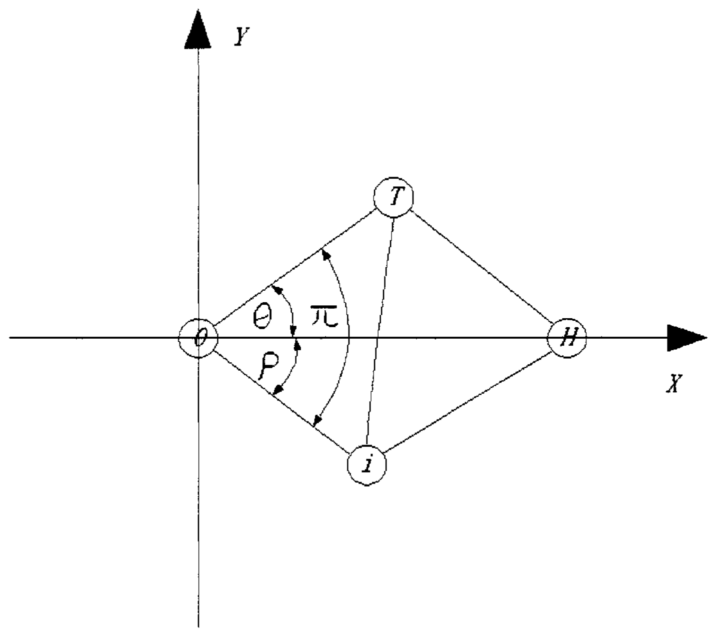


Figure 2-7 Local Coordinate System of node *O*

Shown as Figure 2-7, for any node *i* who is the direct neighbor of *O*, *H*, and *T*, it forms two new triangles *iOH* and *iOT*. Use the formular (2.1) by replacing *T* with *i* and *H* with *i* respectively, we get two new degrees of angles: π and ρ. Then, the coordinate of *i(x,y)* is given by:

$$i(x,y) = \begin{cases} i_x = D(iO)\cos\pi_i \\ if: \rho_i = |\pi_i - \theta| \Rightarrow i_y = D(iO)\cos\pi_i \\ else: i_y = -D(iO)\cos\pi_i \end{cases} \quad (2.2)$$

Consequently, for any direct neighbor *j* of *O* who knows any two of *i*, *H*, and *T*, we can work out its coordinate, and so on.

Network coordinate system

Although the nodes have built up their own coordinate systems individually, the directions of their X and Y axis are not the same. To obtain a unique network coordinate system, the individual coordinate system of each node needs to be adjusted. The adjustment usually includes rotation and mirror, and their combination.

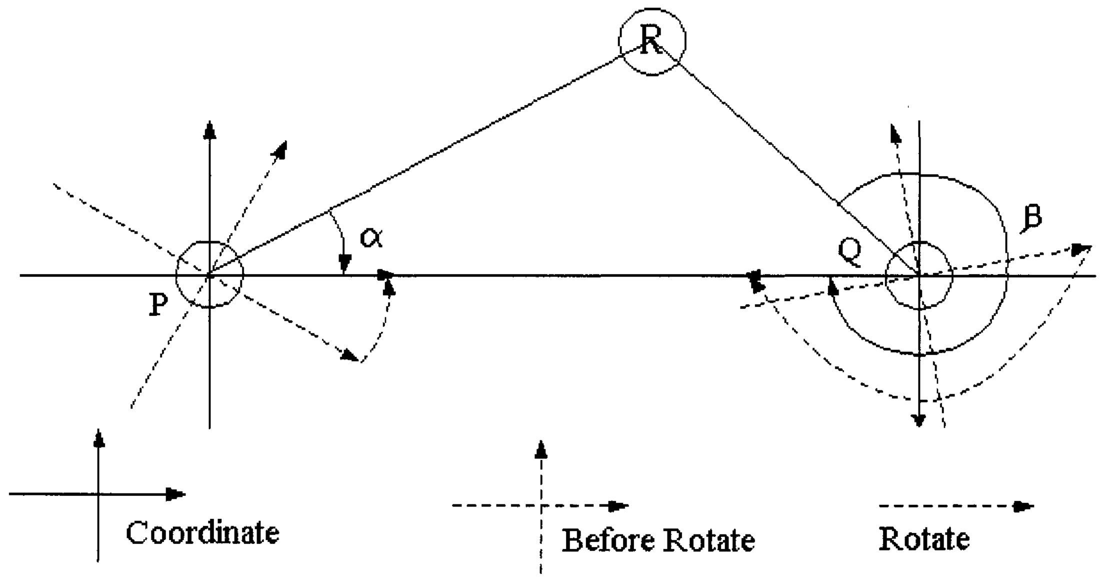


Figure 2-8 Rotation and Mirroring

Two direct neighbors could adjust their coordinate systems according to the edge they have in common. More specifically, node P and Q have the edge PQ in common. The steps are listed below:

1. Rotate the X axis of P's coordinate to PQ, the angle of rotation is denoted as α_P
2. Rotate the X axis of Q's coordinate to QP, the angle of rotation is denoted as β_Q

See Figure 2-8, after the rotations, a node R, who is the direct neighbor of both P and Q, is selected as a reference to see if one of the coordinates needs to be mirrored. We denote the new degree of angle $\angle RPX$ as α_R and $\angle RQX$ as β_R, and then the actual angles of rotation of R in the coordinate of P and Q are:

$$\alpha = \alpha_R - \alpha_P,\ \beta = \beta_R - \beta_Q. \quad (2.3)$$

Then we can tell that if both α and β are greater than of smaller than π, then the mirroring of one coordinate system is necessary; if one of the two is greater than π and the other is smaller than π, then only rotation will fit the needs. In the end, both coordinate systems should adjust the angle of the node in the systems. For mirroring, the correction angle is $\beta_R + \alpha_P$; and for rotation the correction angle is $\beta_R - \alpha_P + \pi$.

In practice, if we regulate the coordinate of any two neighboring nodes, not only the overhead is tremendous but also we could not achieve a uniform coordinate system at all. A more practical methodology is to begin with two centralized nodes and correct other nodes' coordinate one by one.

Because there is lacking of a network coordinate system at the beginning, the selection of the two centralized nodes is somewhat arbitrary. Basically, we can sort the list of nodes by the number of neighbors and begin from the very top of the list to pick out a pair that is neighboring immediately, who has the greatest number of neighbors in summary.

Next, let us adjust the coordinate systems one by one. Assume there is a node K which is a direct neighbor of Q, as indicated in Figure 2-9. The first few steps are exactly the same as what happened between the two central nodes, say P and Q. After the coordinate of K has been rotated and/or mirrored, Q's coordinate is rotated an angle θ back to the direct of PQ. Consequently, K's coordinate is rotated with θ as well. Then, adjust K's location according to Q's location, assuming P is the very centre of the network.

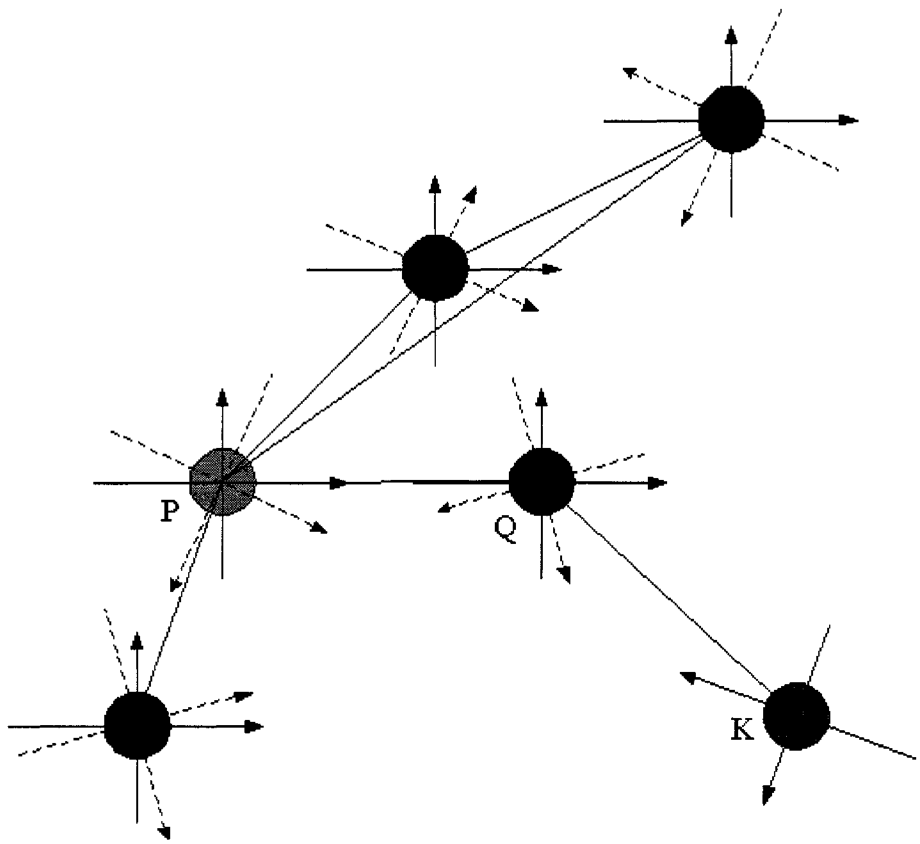


Figure 2-9 Ad Hoc Coordinate System

2.3.2 Ad Hoc Positioning System Algorithm

Dragos Niculescu and Badri Nath in [13,14] have proposed another ad hoc positioning algorithm – the Ad Hoc Positioning System (APS). In this algorithm, nodes are required to have Arrival of Angle (AoA) [15] capability, and distance vector (DV) capability, and some of them are also self-positioning capable.

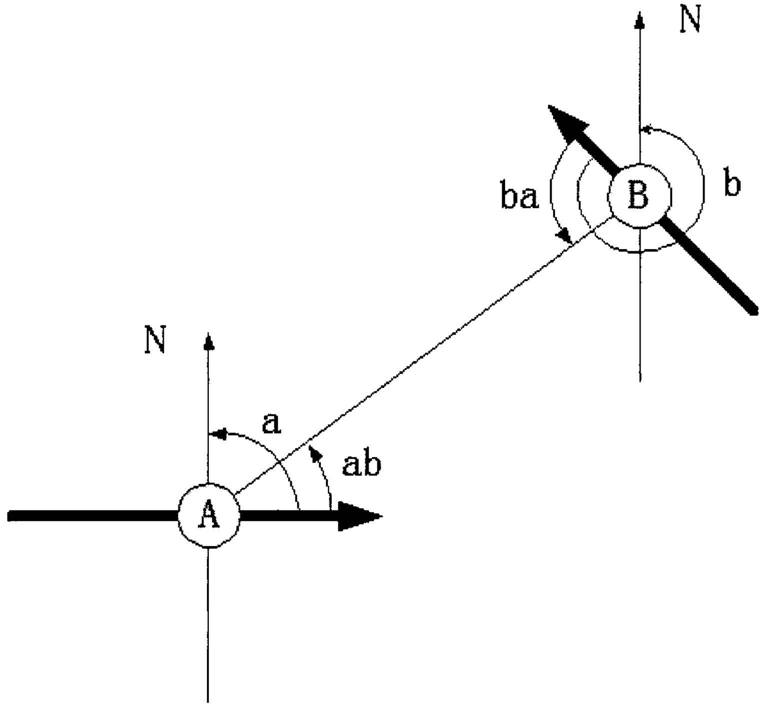


Figure 2-10 Angle of Arrival

The AoA capability refers to the ability that a node could report all direct neighbors' angles against a main axis, see figure 2-10.

This capability is achieved by the combination of a band of technologies. For example, based on both phase difference and time difference of arrival (TDoA), it is capable to calculate the AoA [16]. In Figure 2-11 we can see that two sensors are placed at a distance *D*. The two sensors consequently received a RF signal and an ultrasound signal, which are sent simultaneously. By calculating on the TDoA of the two signals, a triangle is drawn. It is clear that by calculating the angle θ' we could get the desired angle θ eventually.

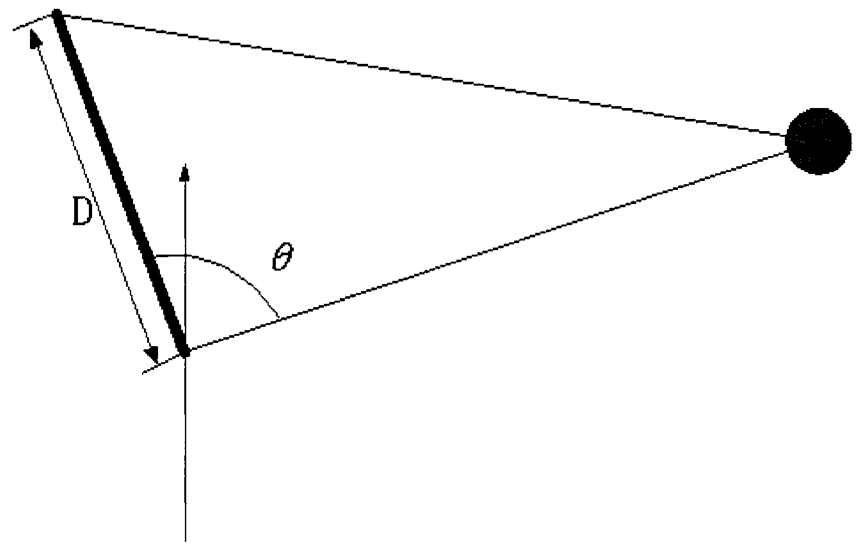


Figure 2-11 Time Difference of Arrival

The DV capability, as mentioned in the routing protocols part, is the ability of a node to reach other nodes in a MANET hop by hop.

The self-positioning ability has no very clear definition. A node equipped with the GPS and could obtain the position and orientation information is considered to be self-positioning capable. A node that could self-position by input by hand is considered as self-positioning capable. A node that is able to reference its own position by some landmark is also considered self-positioning capable.

The algorithm [13] has enumerated six methods to establish the MANET position system:

- DV-hop propagation method, and
- DV-distance propagation method, and
- Euclidean propagation method, and
- DV-bearing and DV-radial propagation method, and
- DV-coordinate propagation method, and
- DV-position and DV-compass propagation methods.

Here we only introduce the first method, the most basic scheme of all. The method contains three stages. In the first stage, the landmark node floods a beacon package with a data structure that records the position information hop by hop. In the stage 2, the updated vector information returns to another landmark node that could perform corrections. In the third stage, a correction parameter is computed for each node in the network for the position correction.

Chapter 3
Location-enhanced On-demand Routing

This chapter analyzes the characteristics of the ad hoc network and deduces some requirements on the desired properties of ad hoc routing algorithm in need. Later in this chapter the Ad-hoc On-Demand Distance Vector Routing is examined as an object algorithm to see to what extent it satisfies the requirements. Consequently, the Location-enhanced On-demand Routing (LOR) is presented as an optimized solution to a current on-demand routing protocol.

3.1 Characteristics of Ad Hoc Networks

When we study the wired network, we always abstract the network into a graph, which is denoted as $G = (V, E)$. G stands for the set of the network and is usually topologically represented as a two dimensional undirected graph. V is the set of network notes, called as vertices in the term of network topology. E is the set of edges between the vertices, which is abstract of connections between nodes. But if we regard an ad hoc network as the study object, the above function turns into $G(t) = (V(t), E(t))$. In this function we can see that graph G, vertices' set V, and edges' set E become variables of time t. At different time, the ad hoc network has different topologies, different set of nodes, and different way of connections. Hence, dynamic topology is the most significant characteristic of the ad hoc network. This characteristic decides the routing in ad hoc network is totally distributed – there is no fixed network backbone to relay on, every node has to function as a router as well as to cooperate with others to provide all network services. Another characteristic affects ad hoc routing is the power conservation of the network. An ad hoc node physically could be a PDA, a laptop computer, a vehicle equipped with computer, etc. Thus it could not obtain constant power supply as its counterparts in the wired network. For the sake of power preserving, the processing capability, storage capacity, and propagation energy have to be limited in an affordable range.

3.2 Desirable Properties of Ad Hoc Routing Protocol

A routing protocol is a set of specifications that defines the rule of packages traveling in the network. Thus the network characteristics have very profound influence on the conceiving of the network protocol. In the field of ad hoc routing, the following nine properties are most concerned when devising ad hoc routing algorithms.

Distributed Operation

Distributed operation means all nodes in the ad hoc network contribute to the routing decision. It is a compulsory property that has to be observed by all ad hoc routing protocols. However, in an ad hoc network, even a node does not participate in a route, its movement might have impacts on the route decision.

Loop-free Transmission

In the network, it happens that a package may be spinning arbitrarily in a circle formed by certain nodes. This is called a loop. In wired network, a loop could be caused by congestion or panic. Unfortunately, loops occur more often in the ad hoc network due to its uncertainties in connections. Although loops in an ad hoc network are at most temporary – circles could be destroyed by the movements of nodes, but it is obvious that loops are consuming bandwidth unnecessarily and hindering the proper delivery of data. Many ad hoc routing protocols are claimed loop-free, yet a hundred percent loop-free transmission is not guaranteed. Some loops are caused by the position shift of nodes and such a situation always happens after the route decision has been made. Thus, when we say an algorithm is a loop-free algorithm, we are referring to its ability to avoid the predictable loops

Scalability

Ad hoc networks vary a lot due to their purposes, sizes, types of physical nodes, etc. This leads to a fact that some existing routing algorithms do not fit ad hoc networks in all circumstances. For example, DSR routing algorithm [1] has a very good performance when the network size is small; but if we increase the size to be very big, the throughput of DSR will decrease to a very poor level because the packages have to include the full path of their routes. A routing protocol that could adapt to all sorts of network situations with an acceptable performance is regarded as a scalable algorithm. Metrics used in the measurement of ad hoc network performance usually include network size, traffic intensity, mobility rate, and network density. By increasing the indices of the measured performance metric, if the routing protocol shows a liner increase in output, then it is considered scalable in this field.

Due to the dynamic nature of ad hoc networks, a routing protocol is highly susceptible to encounter performance decline with respect to certain metric. Hence it is an important issue in the conceiving of a routing protocol.

Multicast

Multicast refers to the ability to send data from one node to many destinations simultaneously. Compared with unicast, which means sending data from one node to another at one time, multicast obviously reduces the using of limited bandwidth in ad hoc networks.

Unidirectional Link Support

In wired networks, all routes are bidirectional, where acknowledgements or piggy backs are sent back along the same route the data packages traveling. However, in the ad hoc network sometimes it is not possible for acknowledgements to travel in reverse way of the data packages. This is because the strength of radio transmitters of different nodes varies. For example, we regard a normal node *N*'s transmission range as *r*, and a more powerful node *M* may have a range of *2r*, then it is possible that *M* could reach *N* but *N* could not reach *M*. In a bidirectional scheme, a route could only be established when *M* and *N* are both in the other's range. Thus, unidirectional link offers more flexible and possibly more optimal routing in the ad hoc network. But as a tradeoff, the computing complexity and management overhead might increase.

Dynamic Route Refinement

Routing protocols tend to calculate shortest paths in order to improve network performance. But experiences tell us that shortest paths are not always optimum. Many of the times, based on shortest paths scheme, some routers are in the way of too many routes and are delaying the packages due to limited processing ability or bandwidth, while other nodes are idle. Dynamically refining routes according to the network status could be a solution to such a problem.

In another phrase, nodes in an ad hoc networks turn to become less efficient due to the movement of nodes. The ability to detect such a circumstance and to refine the route consequently is definitely a desirable property.

Security

Security issues are the most concerned issues in the ad hoc network, because the ad hoc network is more vulnerable to attacks than its infrastructure or wired counterpart. Based on the nature of ad hoc network, attacks are conceived to exhaust mobile nodes' bandwidth, power supply, to degrade CPU processing ability, memory space, or hard drive storage, or to spy information passed by.

Contemporary methods to assure ad hoc security include authentication, confidentiality, and integrity. Nodes in an ad hoc network system authenticate each other could prevent alien node's intrusion. But since ad hoc networks are lacking of a centralized management mechanism in issuing and distributing keys, the complexity of authentication management in ad hoc networks is much higher. Confidentiality means that only the desired recipient in a multicast environment could understand the message, and not for others. This is usually achieved by encryption or modulation/demodulation. Integrity, however, could not prevent eavesdropping from happening, but it could point out if data or instructions have been altered.

Power Conservation

The importance of power conservation is already introduced in the characteristics. So far, a major thought of power saving is borrowed from infrastructure network – sleep. In a personal communication system (PCS), or cellular system, mobile terminals remain in sleep mode to save power until they are awaken by incoming calls. However, in PCS an additional signaling system, System Signaling 7 (SS7) is employed to wake mobile terminals. But in an ad hoc network, where radio bandwidth is in short, employing such a system is too luxury [29]. If a routing protocol could help schedule the nodes' sleeping scheme, it could preserve the power. Another concern is to balance the transmission power among nodes. Obviously, in multicast, a node's range decides the number of nodes that response. Thus, in a condensed ad hoc network, higher transmission power leads to more responses. But this is not to say the lower transmission power the better. In practice, the nodes should tune their power strength according to the network situations. By all means, these two methods are theoretically held, but much too difficult to take into practice.

One more practical way to conserve power is to control nodes' power consuming at routing level [30]. This means power level of nodes should be considered in route decision. Besides the shortest path, or minimal hop number, the least power consumption should also weight in routing. This is mentioned as energy-aware routing.

Quality of Service Support

When speaking about Quality of Service (QoS) of a network, we are usually expecting a high performance on the following indices:

- Availability, higher the average system uptime means better the availability.
- Throughput, the size of data passed per unit.
- Latency or average system delay.
- Cost, from the aspects of resource consuming.

- Packet loss rate, the lower the better.
- Error rate.

QoS support in routing refers to the capability of a routing protocol to poll the performance indices, to analyze the performance, and to optimize the QoS by routing.

Our research initially endeavors to work out an algorithm that possesses all the above desired properties. But however, as the research going on we realized that the novel algorithm will posses most of them, but not all. More specifically, we will support *Distributed Operation*, *Loop-free Transmission*, *Scalability*, *Multicast*, *Power Conservation*, and *Dynamic Route Refinement*. We will indirectly improve the *Quality of Service Support*. But, limitations exist on *Unidirectional Link Support* and *Security* at this stage of research. And they are left to our future research topics.

3.3 Local Position Aided Ad Hoc Routing

Our research in ad hoc routing shows that a portion of ad hoc routing protocol researching is lacking of global views. Many ad hoc routing protocols devote to resolve certain problems identified, and they are proved working well in the areas they are expected to. But on the other hand, drawbacks are found in other aspects, which we have just discussed in scalability issues. As we have seen, proactive protocols are intuitive and easy to implement, but the significant control overhead decreases their performance. To overcome this drawback, on-demand routing algorithms are proposed. DSR, one of the on-demand protocols, tries to eliminate the maintenance overhead of link states by including the full path in the package transmitted. The result is, at the same time of reducing beacons, the DSR package size grows with the network size and makes DSR not scalable in medium and large size ad hoc networks. Such an example is not alone in ad hoc routing research.

Thus, we follow an alternative routine than the above one. That is to apply a new point of view on the base of existing algorithms to achieve optimum. And the achievements are made without sacrificing existing performances.

3.3.1 Global Position vs. Local Position

In this work, we categorize traditional proactive and reactive protocols that do not need to be aware of mobile nodes' positions as location unaware protocols. These protocols are mostly suffered from control overheads. One thought on eliminating beaconing and flooding is to let every nodes know the network topology at any time it need to transmit a message. It is easy to say so but hard to realize, as the ad hoc network itself is lacking such a mechanism to refresh topology at each node. Location based protocols provide a solution to this problem – by knowing the location of all other nodes in the ad hoc network, a node could work out the topology and make more smart route decisions. This thought sounds promising and feasible - currently several positioning systems are available, i.e. the sonar system, the RADAR system, the GPS system, and Cellular geolocation system [12].

Most location based protocols refer the GPS service for position information. But the feasibility of employing GPS in the ad hoc network is worth questioning. Our research indicates there are four significant drawbacks of using GPS in ad hoc routing. First, the accuracy of current GPS is not high enough. In North America, the Standard Position Service has an accuracy of 100 meters, which is far away from the need of ad hoc routing. Second, the GPS requires that the object has direct sight access to three satellites, which is unfavorable for ad hoc networks that deploy in urban areas or in valleys. Third, the power consuming problem is also preventing the GPS to be adopted. It is hard to imagine of installing a GPS terminal on a laptop. Last, the body size of a GPS terminal is too big, as it requires a disc to receive satellite signals.

To avoid the limitations of global position, in this work we propose to replace global position with local position in aiding ad hoc routing. In fact, local position information is more intuitive than that of global position. When you know two nodes' global positions and you want to know if they are neighbors, you have to use certain formula to calculate. But if you have a node's distance to another node, you will know if they are neighbors immediately.

The acquaintance of local position information is also much simpler than that of global position information. Even with an ordinary omni-directional antenna, local positions of objective nodes could be detected with Angle of Arrival (AoA) and Time Difference of Arrival (TDoA). In addition, an antenna is mandatory to a mobile ad hoc node, while the GPS terminal, which is just an optional accessory. Thus, in this work, to help more accurate positioning, we recommend to use the smart antenna.

A smart antenna is an array of antenna elements connected to a digital signal processor, in which certain algorithms are employed to process and filter signals collected, in order to improve the quality of communication. A smart antenna usually has four features: signal gain, interference rejection, spatial diversity, and power efficiency [33]. When using smart antennas the network will have access to spatial information about the users [34]. This information can be used to estimate the positions of the users much more accurately than in existing networks. D. R. Van Rheeden et al. [25] introduced an algorithm that uses a single base station to position mobile terminals in a mobile network.

Figure 3-1 demonstrates how a smart antenna gets aware of a mobile terminal's position. When radio signals arrive at a smart antenna, the antennas in the array collect information as AOA, TDOA, and phase of the signal at arrival. The information is processed at the digital circuit connected. Location information is finally output to the host mobile station or terminal.

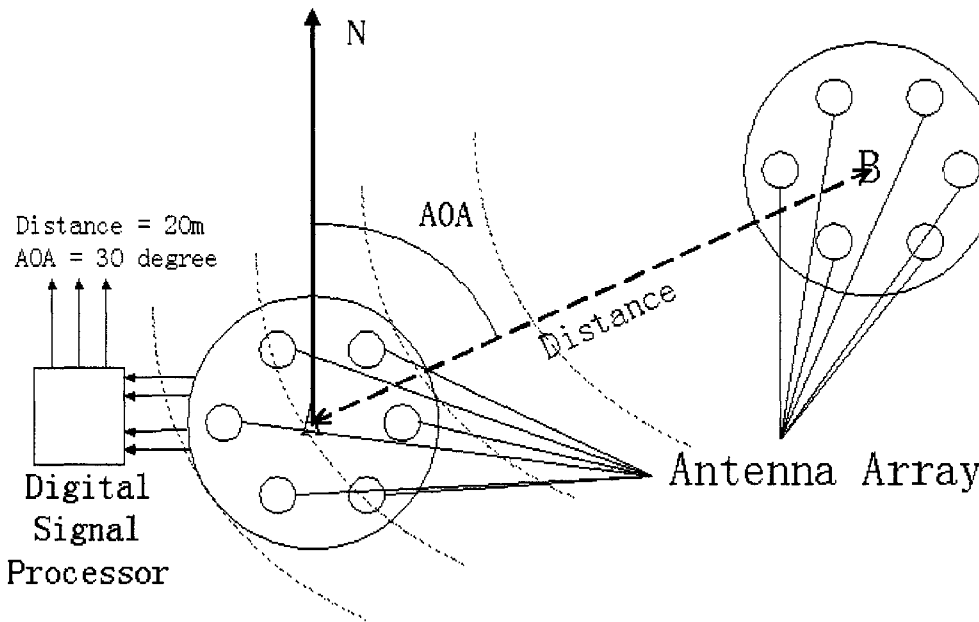


Figure 3-1 Locate Mobile Node with Smart Antenna

The smart antennas are able to locate the mobile nodes in its range only. Thus, in a local position based routing algorithm, a node knows only its neighbor's status of connection and relative position. Thus the route decision based on it is much easier and simpler. The scheme of a global position based algorithm is significantly different. A node in such a scheme synchronizes the global positions throughout the network, calculates the network coordinate, works out the connectivity map, and makes route decisions in the end. This makes the decision very complex and difficult.

3.3.2 Assumptions and Properties

There are two assumptions made before we go on with the algorithm:

Assumption 1*: *We assume that all mobile nodes are equipped with smart antennas, hence they are orientation capable. More specifically, they are able to identify their neighbors' relative position by incoming radio waves from them. As figure 3-1 shows, when node *A* receives radio signals from *B*, the smart antenna on *A* knows immediately the direction and distance of B.

Assumption 2*: *We assume that all nodes are north aware, which means they know the direction of north. However, north aware is not a compulsory as we have known from [3] introduced in Chapter 2. Sometimes, some or all of nodes may know their global positions from references. This of course will significantly reduce the complexity of positioning, but is not included in the assumptions.

An important property of the above assumptions is:

Property 1: Equipped with a smart antenna, a node could be aware of its neighbors' relative velocity.

The same way of a RADAR system to detect the speed of a moving vehicle [22], a mobile node with a smart antenna is able to know its neighbor's movement by calculation. Upon receiving two consequent signals from its neighbor, it knows that at time t its position is at p_1 and at time t' the position is p_2. Thus, its neighbor's velocity vector $\vec{v}$ observed through the two consequent incoming radio signals could be expressed as the following equation:

$$\vec{v} = \frac{\overrightarrow{p_1 p_2}}{t' - t} \quad (3.1)$$

If the time interval is small enough, this equation becomes the derivative of the objective nodes' speed vector. See Figure 3-2, if we regard node A as relative static, then we could work out node B's relative movement to A.

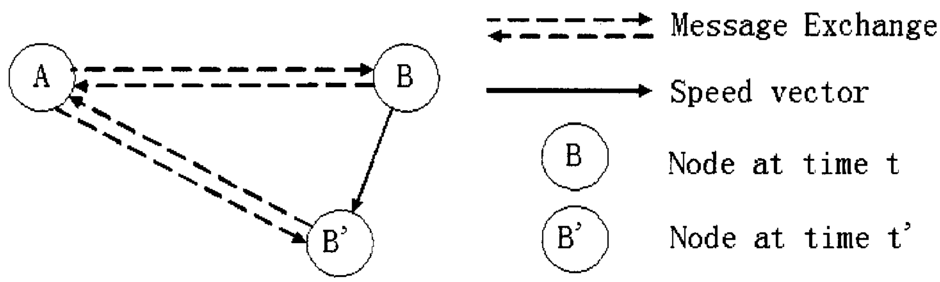


Figure 3-2 Relative Speed of B to A

Based on *Property 1*, another important deduction could be carried out:

Property 2: A node is able to estimate how long it could keep connected with its neighbor.

From *Property 1*, we know that node *A* could get to know its neighbor *B*'s relative position *p* and relative speed vector $\vec{v}$, as indicated in Figure 3-3. We assume *B* travels straight forward along the direction of the velocity vector $\vec{v}$. Then it will cut the range circle of *A* at the point *C*. *AC* is a radius, the length of AB is detected by the smart antenna as *d*, and the degree of angle θ is known. So, according to the triangle law, the distance of d_{BC} follows the equation:

$$r^2 = d^2 + d_{BC}^2 + 2dd_{BC}cos\theta \quad (3.2)$$

and by resolving this equation, eventually we get d_{BC} Hence, the possible time of connection $t = d_{BC}/|v|$, where $|v|$ is the absolute value of speed $\vec{v}$.

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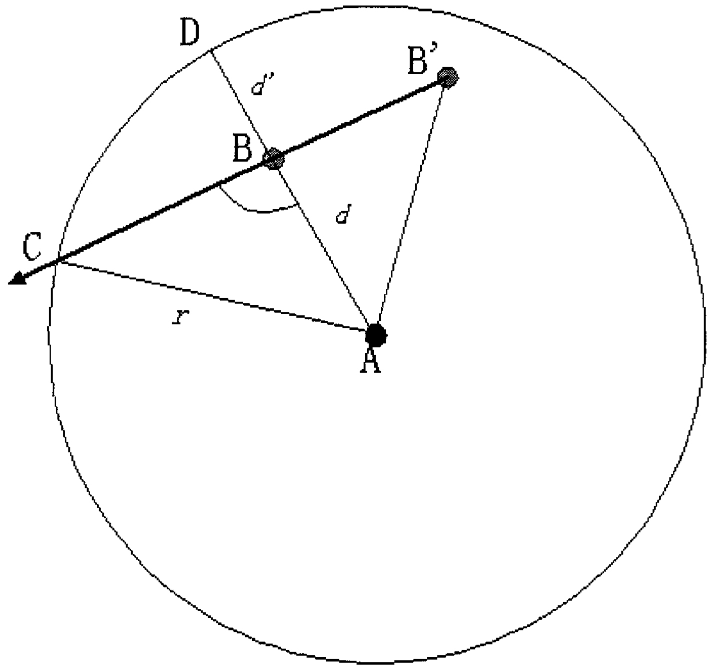

Figure 3-3 Estimate Time of Connection

Property 2 reveals a very interesting result – in an ad hoc network, control messages such as global position synchronization beacons or periodical *hello* messages are not necessary in such a context. Let's consider a route *R* in an ad hoc network *N* of *M* nodes ($M \geq 2$). The intermediate nodes are denoted as $r_i \in R$ ($i=0,1,\ldots,n-1$, where *n* means the number of nodes in *R* and $M \geq n \geq 2$. Once R is established, data packages, piggybacks, and acknowledgements are exchanged in between. This enables r_i to update its neighbors' local position and time of connection information dynamically. Therefore, there has no need of beacons that synchronizing positions, or *hello* messages to test link states.

3.3.3 The Location-enhanced On-demand Routing

In section 3.3.1 we proposed to use local position in aiding ad hoc routing. But, how to use it? And what will be the performance and advantages? To answer such questions, in this section, we present a novel ad hoc routing algorithm, the Location-Enhanced On-demand Routing (LOR), to demonstrate how local position could help ad hoc routing.

The main purpose of the LOR is to eliminate network control overheads as much as possible. To achieve this goal, the LOR employs local positions in aiding route decision, induces a set of new mechanism to take of the location information, and involves only participants in a route to synchronize location information. As a reactive protocol, the LOR is prototyped from the Ad-hoc On-demand Distance Vector (AODV) routing protocol [18]. Architecture of the LOR algorithm is shown in Figure 3-4.

Following in this session, we introduce the behaviors of the LOR stage by stage. As in a reactive routing protocol, usually there are three stages: Route Searching (RS), Route Establishment (RE) and Route Maintenance (RM). The Route Research includes two phases - Route Request and Route Reply. To show our work based on the AODV, at each stage we first recite the behaviors of the AODV, then briefly analysis the problem facing, and present the LOR's solution in the following.

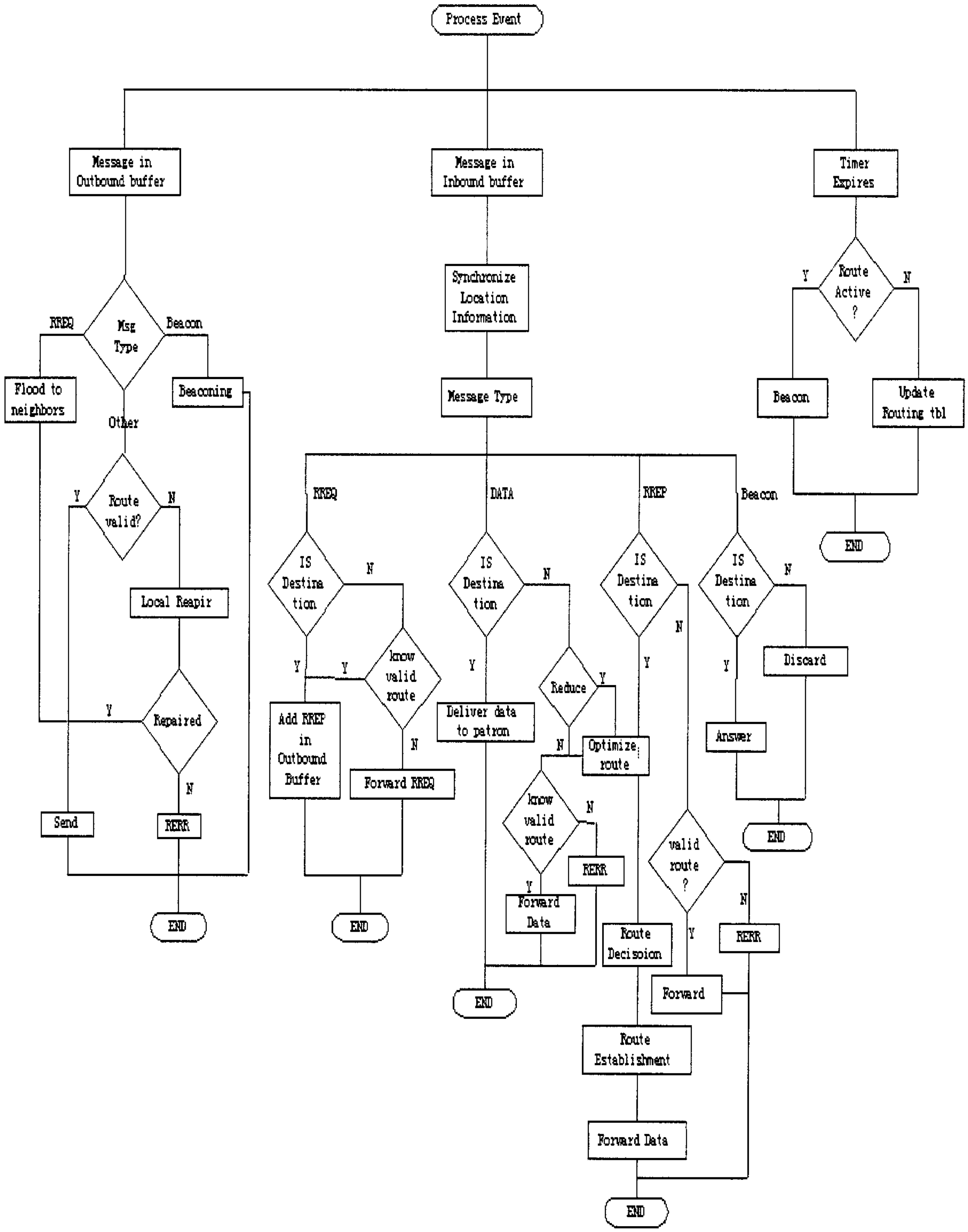

Figure 3-4 Location-enhanced On-demand Algorithm

Before we get started with the LOR, a table is give as a brief survey of the differences between the LOR and the AODV to help better understanding of the algorithms.

Table 3-1 AODV vs. LOR

Stage	AODV	LOR
RREQ	• Flood	• Flood, without knowledge of destination. • Restricted flood, with knowledge. • Synchronize network coordinate
RREP	• Receive and forward RREP.	• Receive and forward RREP • Synchronize network coordinate
RE	• Upon the first RREP	• Calculate *degrees of connectivity* • Choose a more stable route rather than a fragile one
RM	• Periodically beaconing • Send RERR upon route failure • Re-flood upon RERR	• Dynamically optimize the route by Route Reduce • Monitoring if the route is active • Beaconing according to connection status • Local repair • Re-flood if Local Repair not successful.

3.3.3.1 Route Request

The LOR has two scenarios in the RS stage – flooding and limited flooding [11]. The applying of the scenario depends on the knowledge of the source node to the destination node. If the Source has no knowledge about the Destination's position, then it floods over the network. Otherwise, it applies limited flooding.

The flooding algorithm is the same as that of the AODV protocol. The Source initiates a route request (*RREQ*) message and floods it in the MANET. The message is uniquely identified by the Source Node Identifier (*SID*), Destination Node Identifier (*DID*), and Sequence Number (*SEQ*). Intermediate nodes receive and forward the *RREQ* to their next hop direct neighbors. To avoid the loop, Intermediate nodes compare *SID*, *DID*, and *SEQ* to check if the message has been previously received. Intermediate nodes discard redundant *RREQ* to assure the algorithm is loop free.

As a location based algorithm, the LOR is able to take the advantage to adapt the limited flooding when location information of destination nodes is available. It restricts the flooding only be happening in the Request Area. This area, as introduced in Chapter 2, includes the source *S* and the Expected Area of the destination *D*, see Figure 2-5. The nodes which are out of the Request Area discard the *RREQ*. The limited flooding also uses receive and forward strategy to pass the *RREQ* and uses the <*SID, DID, SEQ*> vector to avoid loops as well. For details of this scenario, please consult section 2.2.1 of Chapter 2.

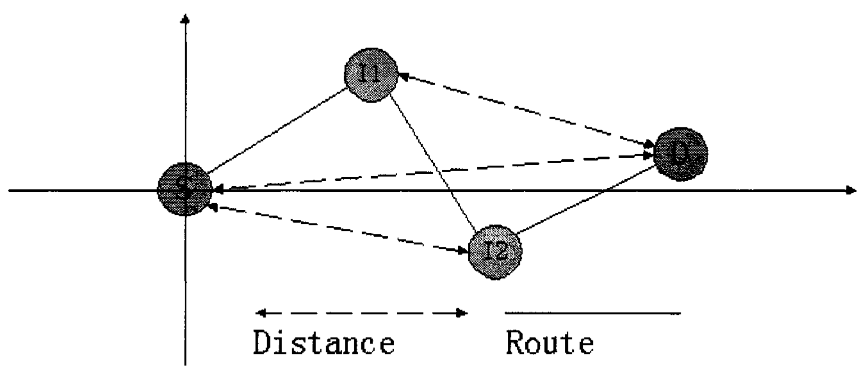

Figure 3-5 Network coordinate

In the AODV routing algorithm, flooding is used to explore the network to establish connections between nodes. But in the LOR, the flooding is assigned with one more task – to synchronize the location information throughout the network. In the beginning, the Source *S* put its location information as $P_S(0,0)$ in the *RREQ* since it has no knowledge or poor knowledge of the nodes distribution in the network. This position information is updated hop by hop until arrives at the destination *D*. And the initial location information is established and synchronized.

Figure 3-5 shows a simple example that involves four nodes. We will go through this example to explain the synchronization procedure. We define the neighbors of a node to be a set *K*, and K_S stands for the set of node *S*'s neighbors. At the first step, the neighbor of the source S, I_1 ($I_1 \in K_S$), receives the *RREQ*, it updates the location information of *S* according to its own coordinate. Next, for I_1's neighbor $I_2 \in K_{I1}$, it updates the location information based on the position information of *S* it receives and the relative position of I_1 in its own coordinate. The calculation of relative is as formula (3.3):

$$P_S^{I_2}(x_S^{I_2}, y_S^{I_2}) = P_{I_1}^{I_2}(x_{I_1}^{I_2}, y_{I_1}^{I_2}) + P_S^{I_1}(x_S^{I_1} + y_S^{I_1}) \quad (3.3)$$

$$\therefore P_S^{I_2}(x_S^{I_2}, y_S^{I_2}) = P_S^{I_2}(x_{I_1}^{I_2} + x_S^{I_1}, y_{I_1}^{I_2} + y_S^{I_1}) \quad (3.3.1)$$

where P_S^I means the relative position of *S* in *I*'s coordinate, and x_S^I and y_S^I are the values of *S*'s position on the x and y axis of coordinate of *I* respectively.

Like a ripple, the location info is synchronized throughout the network. Eventually, when the *RREQ* reaches the destination *D* in the end, *D* obtains the position of *S* from nodes who forwards the *RREQ* to *D*. The synchronized location information helps the nodes to establish their local network coordinately, and this is important to the future route decision.

3.3.3.2 Route Reply

Upon receiving the *RREQ*, the destination *D* reacts by initiating a Route Reply message and sends it back to the source *S*. The initiation of the *RREP* has 3 steps:

1. The destination D opens the *RREQ* and learns the routing and positioning information.
2. By calculation, D knows the relative position of the source S and the direct neighbor J.
3. Then D encapsulates the location of itself and S into the *RREP*.

Now, before the *RREP* is sent to the next hop J, the selected route between D and S is just a unidirectional route, which means each node in the route knows only its next hop to the source S, but has no knowledge from S to D. While the *RREP* traversing the route back to S, a bidirectional route is established. Same as in the delivery of *RREQ*, the destination D set the location information of itself as $(0,0)$, and the location of the source S as (S_x,S_y), as it obtained by calculation. The next hop node J interprets the location information into its own coordinate and updates and forwards the *RREP* to the next hop. Finally, the *RREP* reaches the source S, and a bidirectional route is merely established.

3.3.3.3 Route Establishment

In the AODV routing protocol, upon the source S receiving the first *RREP*, the route is connected and S begins to send packages to D along the path. This is obviously the fastest way to build up connections, but maybe not the optimum way. As shown in Figure 3-8, a redundant path maybe established. Another problem is that the established route could be fragile due to the highly dynamic nature of the ad hoc network. In a greedy scenario of *RREP*, the destination D replies only to the first *RREQ* received from S and sent a *RREP* back. Such a route usually has a minimal hop numbers and a relatively shorter distance among all candidate routes. But the intermediates nodes also have longer distances in between. Possibly, a node B is bridging at the middle of the range of two other nodes, say A and C, see Figure 3-6. Any movement of B leads to the disconnection of A and C. And consequently breaks the route. Obviously, if such a circumstance happens, the source S has nothing to do but floods again over the network.

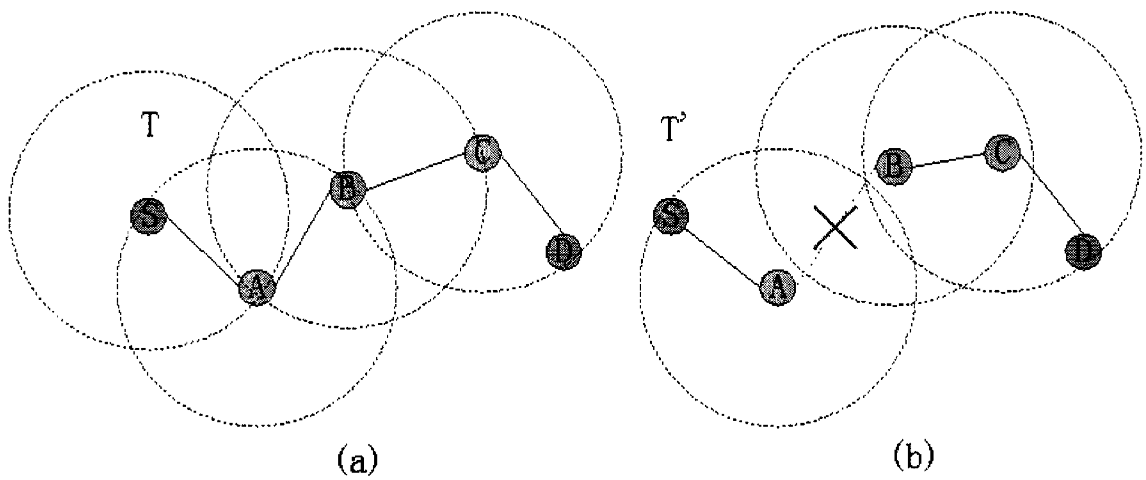

Figure 3-6 Movement Leads to Disconnection

Location-enhanced On-demand Routing optimizes the route establishment strategy by taking the advantages of location information. It suggests a more stable path rather than a capricious one. When we refer a route to be more stable, we mean all the nodes in the route could stay connected with its neighbors for much longer in time.

From the *Property 2*, a node is capable of estimating its neighbor's time of connection. Here we discuss this problem in further detail. In this work, we call the estimated time scaled by millisecond as the *Degree of Connectivity*. Hereby we denote the *Degree of Connectivity* of node *A* to node *B* as C_{AB}, see Figure 3-3. From the function (3.1) we know that a location capable node, namely *A*, could be aware of his direct neighbor *B*'s relative speed $\vec{v}$. Let us denote the range of a node as *r*, the distance between nodes *A* and *B* as *d*. Then the *Degree of Connectivity* (*DoC*) of *A* to *B*, C_{AB}, could be interpreted as the following function:

$$C_{AB} \geq \frac{r-d}{|\vec{v}|} \quad (3.3)$$

where $|\vec{v}|$ is the absolute value of the speed $\vec{v}$, *r-d* is denoted as *d'* in Figure 3-3, which stands for the shortest way for *B* to escape the range of *A*. This function means that B will stay connected with A for at least C_{AB} milliseconds at current speed. And for the easiness of calculation, we use function (3.3.1) to estimate C_{AB}:

$$C_{AB} = \frac{r-d}{|\vec{v}|} \quad (3.3.1)$$

Knowing the the *DoCs* of all nodes in a route, then we say that the smallest *DoC* among the entire route. This is done during the stop-and-forward of the *RREP*. Once a node receives a *RREP* from its predecessor, it compares its *DoC* with the *DoC* field of the *RREP*. It updates the field if it finds its *DoC* is smaller. For example, as shown in Figure 3-3, if we set the *DoC* of *S*, I_1, I_2, and *D* as C_{SI1} = 3000, C_{I1I2} = 2200, C_{I2D} = 2400, thus from *D* to I_2 the *DoC* field of RREP = 2400, from I_2 to I_1 it turns to be 2200, and remains no change when the RREP arrives at *S*. By this way, the algorithm ranks a route with the highest *DoC* as the most stable route.

Knowing the *DoCs* of neighbors also helps a node to reduce unnecessary beacons, either periodically or desired, which is discussed in next section.

3.3.3.4 Route Maintenance

Error may occur during the Path Discovery stage. The source *S* may not be able to reach the destination *D* at all. Or the bidirectional route suddenly breaks right after the *RREQ* is forwarded. Under such circumstances, intermediate nodes and the destination node do not take the responsibility to repair the route in building. Same as in AODV, the source *S* takes care of the route establishing only. By setting a timer, S waits for a *RREP* until the timer expires. If the desired *RREP* arrives before the expiration of the timer, a route is then set up. Otherwise, S reinitiates a *RREQ* with a newer sequence number to the destination to take place the previous sent one.

Routing table maintenance

After the source S and the destination D have exchanged a *RREQ* and *RREP* pair, the communication begins. For any node $i \in L_{SD}$, where L_{SD} is the set of intermediate nodes between S and D, it maintains a routing table for the requirement of current and future routing between S and D. The routing table includes the following information:

- The destination D
- The time stamp of the last packet from D
- The next hop node
- Number of hops
- Sequence number for the destination
- Connection degree of last hop node
- Expiration time for the route table entry

When the destination D sends a packet to S along the route R, each node in the route update its routing table entries upon receiving a package. A local system time stamp is also attached with the updated entries. This parameter interprets how active a node is in the routing. At the same time, the nodes update the *DoCs* and reset the timer according to the time stamp. From the stamped time on, the timer is set to the new *DoC* value and will be expired when becomes zero. During this time interval, the node does not have to say hello to the connected neighbor in order to check the link state. This is a way how the LOR reduces control overheads.

Route Reduce

Overtime the nodes move and the topology changes. This makes it possible that the route becomes zigzag and deserves to be optimized. Figure 3-7 (1) indicates that node R is bridging between node P and Q. In Figure 3-7 (2) we see that P and Q become direct neighbors, so the existing of *R* in the route from the source *S* to the destination *D* seems not necessary. The Location-enhanced On-demand Routing is an intelligent algorithm that can optimize the route during the communication. There are two types of route reduce in Location-enhanced On-demand Routing, namely Head Reduce and Hop Reduce.

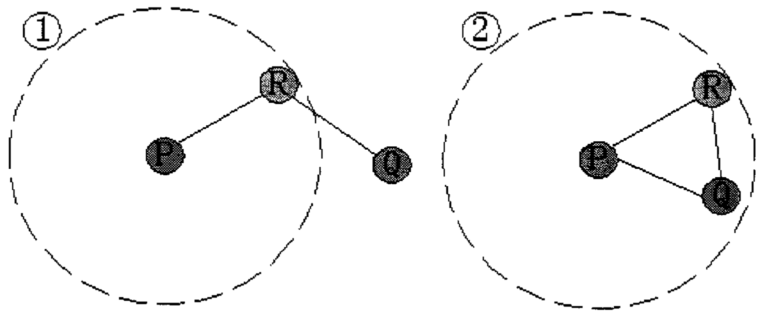

Figure 3-7 Movement Cause Intermediation Unnecessary

Head Reduce: The Head Reduce happens between a head node and any of an intermediate node. When we say a head node, we refer to either the source node of the destination node. In an ad hoc network, it happens that some intermediate nodes are in the range of head nodes at the same time. Hence a shortcut may reduce some redundant nodes. Two scenarios may cause the redundant path. The first scenario is shown as Figure 3-7, movement leads to a shortcut. The second scenario is in the path discovery, when the Source floods the network it establishes upon the first route reply. If an intermediate node that knows the destination replies before other nodes, then a path is established. But this path may not be an optimal one, see Figure 3-8. According to the Path Discovery procedure, the intermediate nodes know the relative positions of both the source *S* and the destination *D*. Thus they know the distances of *S* and *D*. An intermediate node then compares the distances with its own range and finds out if *S* or *D* is immediate neighbors. Under such a circumstance, the intermediate node beacon the destination directly to setup route establishment by a hello message. After that, when data package passes by, it goes from the intermediate node along the newly established shortcut. Hence the redundant route is reduced.

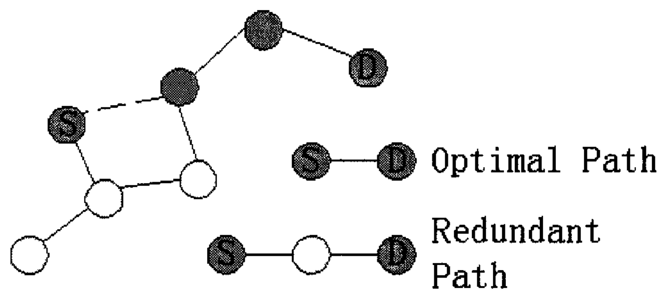

Figure 3-8 Redundant Path

Hop Reduce: In practice, many redundant paths are not head-reducible, see Figure 3-9. However, a shorter path exists, which has only four hops, but a longer path with 6 hops is in use. In the AODV, it is not possible to detect such a redundant path. But the LOR has a way to check if a route is too long, by taking the advantage of location information – the Hop Reduce.

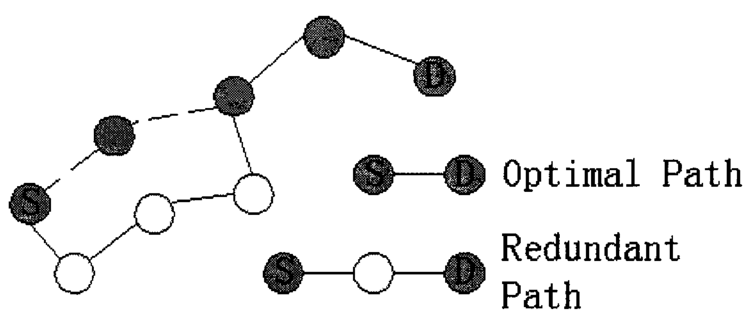

Figure 3-9 A longer path

The Hop Reduce is a more complex procedure. It happens in case when a redundant path is detected but Head Reduce is not applicable. It takes three steps to perform a Hop Reduce:

1. Information collecting
2. Redundancy checking, and
3. Path optimizing.

Information checking is the easiest step – it collects the hop number of the path and the distance between the source and destination. This is done during the location information synchronization. For details, please consult section 3.3.3.1 and 3.3.3.2.

Redundancy checking is the most difficult part of Hop Reduce. In this step, the algorithm estimates a reasonable number of hops according to network parameters, and then decides if current path is too long. A model is proposed in this work to estimate the 'reasonable number of hops', see function (3.4):

$$n_{hop} = \left\lceil \frac{dist(S,D)}{\alpha R} \right\rceil \qquad (3.4)$$

where n_{hop} is the 'reasonable hop number' estimated, $dist(S,D)$ is the distance between S and D, R is the range of nodes, and α is a weight and $\alpha \in (0,1)$. The weight α is related to the density of nodes of the objective ad hoc network, and the higher the density, the lower the value of α.

This model interprets an estimation of possible number of hops in a route that expands the distance $dist(S,D)$. If the density of the network is higher, then a route may involve more nodes. This model implies the possibility of refining the route dynamically with the aid of position information, which is beyond the range of our research in the moment, and left to one of our future research jobs.

Next we compare the actual hop number and estimated hop number n_{hop}. If the difference is greater than what we expected, then trigger a Hop Reduce Query to search for a more optimal route.

At the last step, the Hop Reduce Query evokes a limited flood to search for a better path between S and D.

Route Maintenance

In AODV, the algorithm keeps a route by periodical sending hello messages to neighboring nodes. This obviously increases the network overhead. In the LOR, no periodical beaconing is needed. The nodes know the possible connection time of their neighbors. Only a node estimates its neighbor is out of reach causes a beacon to verify the connectivity between them. One thing has to be mentioned in the Route Maintenance phase is the local repair subroutine.

Local Repair vs. Two Hop Repair

The definition of local repair is interpreted as "the intermediate node attempts to repair the link break itself by sending a *RREQ*" in [18] by Elizabeth M et al. Here in the description of Location-enhanced On-demand Routing, the meaning of Local Repair refers to the same procedure. But as Location-enhanced On-demand Routing is very sensitive to the connection status of neighboring nodes, we can expect to take this advantage to minimize the *RREQ* mentioned above to a two-hop beacon message. See figure 3-10. Although the neighbor of *A*, say *B*, is running out of the range of *A*, another neighbor *C* could bridge *A* to its destination *D*. So, if *A* query its neighbors, it is very possible to repair the link.

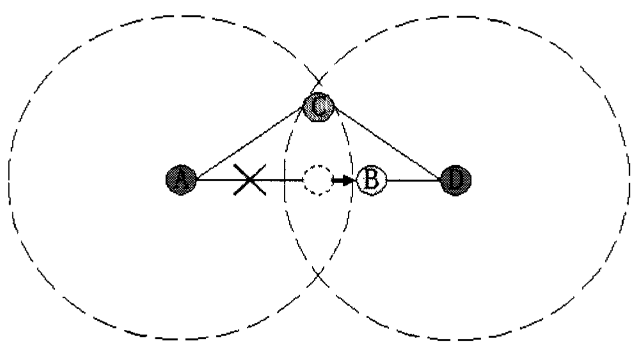

Figure 3-10 Local Repair

However, local repair is a dangerous strategy. As in a local repair, a loop may be built because nodes are lacking of a global view of the MANET. For example, as in Figure 3-6, if node *A* knows a node *C* who has a route to *D*, but actually *C* has to refer to an *A's* predecessor to *D*, then a loop appears.

A safer local repair strategy proposed is the Two Hop Repair. It could be regarded as a restricted local repair. First it only tries to locate the previous next hop node other than any node who knows the destination. Second it uses a special beacon message, called two-hop beacon, which only propagates twice, to locate its previous successor.

Chapter 4
Simulation Model and Results

This chapter presents the simulation model to analyze the performance of the algorithm proposed, namely, the LOR. A detailed description of the establishment of the model is given in this chapter. Input and output parameters are defined, and simulation results are presented and analyzed.

4.1 Simulation Model

The main objective of the simulation model was to provide a neutral, systematic analysis of the performance of the Location-enhanced On-demand Routing, and to gain a deeper insight into the inherent characteristics of location based reactive routing. This section presents a discussion of the simulation environment, design of the simulation, and analysis of the mobility model and system parameters selected to achieve the goals of the analysis.

4.1.1 Ad Hoc Network Modeling

In order to further study networks and design algorithms for their functions, we utilize a model for the network. This is a schematic description, imitating the topology and the inherent characteristics of the ad hoc network. The model proposed need to be realistic, closely reflecting the real network. Simultaneously, it should not be over complex. Too complicated network model may be difficult to design, and even impede the study of the network it is meant to assist.

In general, networks can be visualized as graphs. As introduced in Chapter 3, the graph of an ad hoc network could be interpreted as $G(t) = (V(t), E(t))$.To model such a dynamic ad hoc topology, we shall first examine the modeling of a stationary instance, and subsequently present mobility modeling techniques. A graph is therefore employed to provide the basic structure of a network model in the following way.

In the most common and intuitive way, stations are modeled by nodes, as we already know. Stations have various transmission ranges. A node is considered as direct neighbor of another if the Euclidean distance between their coordinates in the network is less than its minimum transmission range. Under such a circumstance, the participating vertices are connected by an edge in the graph model. This graph is an undirected graph if the object ad hoc network is not unidirectional route supported. An ideal case of such a model is to normalize all transmission ranges to be equal (or if we minimize over all of them), and such a graph is called a unit graph. A unit graph is obtained by systematically linking pairs of nodes.

4.1.2 Mobility Model

A mobility model resolves the problem of imitating the actual movements of the ad hoc networks in the real world. To build such a model, the most straightforward way is to trace the movements of the stations in a real ad hoc network and then abstract the moving pattern. In this way, the movement of a large number of stations has to be observed for a long time, to gain useful information. Further more, the mobility patterns are clearly application dependent. Obviously, such a mobility model has limitations, for the moving patterns of ad hoc networks vary a lot. For example, the mobility of vehicles in a city suburb would be of high speed, but restricted on the grid formed by the roads, whereas sensor devices scattered in the air would possibly have no surrounding obstacle restriction in their movement. Instead of tracing the real network movement, T. Camp et al. [32] have proposed the synthetic model to mimic actual mobility models as close as possible. This model first defines the entities' mobility models, and then applies different group mobility models to entities in groups. The synthetic model is no doubt a better choice of mimicking all sorts of ad hoc mobility patterns.

As the LOR is to be extensively examined in all circumstances, it should not be applied with a specific group mobility model. Thus the simulation mobility model will not consider the group mobility model. And this will not degrade the simulation result as any of a group mobility model movement is a subset of a totally random memory-less mobility model.

4.1.3 Entity Mobility Model

Entity mobility models represent mobile nodes whose movements are statistically independent of each other. They are also called Independent Mobility Models. In my research, two of the Entity Mobility Models are referenced to build the ad hoc mobility model – Random Walk and Random Direction.

Random Walk

The Random Walk mobility model was introduced in [35]. It was developed to imitate the erratic movement of physical entities. This mobility model adopts several basic assumptions:

- Consecutive time intervals of movement give way to one another for each node independently.
- The motion is restricted to move along a line.
- Each node moves at only one speed at any time, which means that it has zero acceleration.
- The movements only occur either during discrete intervals of time, or until a fixed distance is traveled.

In this model, the direction, measured in degrees and the speed of the movement are chosen randomly from predefined ranges. If a node hits the boundaries of the region of the graph representing the network, it bounces back in.

Random Direction

This is achieved by randomly selecting a direction, measured in degrees, rather than a position in the area. The direction meets the boundaries of the area at a specific point.

This point is chosen as the destination of the node. The speed is selected in a uniformly random manner, and the mode travels to its destination at the given speed. Once it reaches the destination, it pauses for the predetermined pause time, and then selects a new direction.

The chapter concludes with discussion of the metrics we chose for analysis and the experimental approach used for sensitivity analysis and comparison of the two routing paradigms.

4.2 Simulation Design

In this section a simulation model is established in C++ language to evaluate the performance of the LOR. A detailed description is given, and input and output parameters are also defined and assigned with appropriate values.

4.2.1 Input Parameters

The following input parameters are required in the simulation:

- Area: All nodes are generated initially within a certain area of $1000 \times 1000 m^2$.
- Transmission rate: All nodes can transmit messages at the rate of 1Mbps.
- Transmission range: Each node can transmit messages in the range of 250 meters. Only those nodes that are in the range could hear the transmitted message.
- Speed: All mobile node moves at the same speed, the speed could be 1m/s, 10m/s, and 30m/s.
- Direction: Each node moves at a direction randomly selected from any 1 out of 360 degrees. The direction changes every 1 millisecond.
- Packet size: Each packet has a size of 1Mb.
- Traffic load: Poison process, at a average arrival rate of 1Mbits/secomd, data arrival is totally random.

- Buffer: Each node has two buffers, the input buffer and the output buffer. The both buffers are all unlimited buffers.
- Number of nodes: 50, 100, and 400 nodes will be generated respectively to evaluate the performances in different cases.
- Iteration number: Program runs in iterations. The iteration number should be big enough to show the network performance in a stable status. A number of 100,000 is set arbitrarily after experiments.
- Beaconing interval: The confidential interval that no beaconing should be sent in between. This interval is adjustable, according to different moving capability of the network.

4.2.2 Output Parameters

The following output parameters are required in the simulation:

- Average end-to-end delay: the average end-to-end data delay is the mean delay involved when a packet traverses the path to its destination.
- End-to-end throughput: the end-to-end throughput is the probability that a packet reaches its destination.
- Power Consumption Ratio: consumptions of power on watts per kilobits message, assuming each transmit cost 1 watt of power.
- Generation overhead: the total number of control messages generated in the experiment divided by total number of messages generated by all nodes.

4.3 Simulation Procedure

4.3.1 Assumptions

The simulation is based on the following assumptions:

- The network follows a random graph model, in which nodes are placed randomly in a given region.
- All the nodes are identical, but they function independently.
- Each node independently decides its movement, including the direction and

speed.

- Data and control messages have the same priority.
- A node can receive as many as possible packets but only send one packet.
- A control message and a data message have the same processing time.
- Links are bi-directional.
- Each data package requires an acknowledgement before next one is sent.

4.3.2 Simulation Data Structures

Message Data Structure

A message object in the simulation has the following data members in its data structure:

RequestType: Indicate the type of the message; the type could be RREQ, RREP, RERR, DATA, ACK, and BEACON.

SID: The universal id of the source node in the objective ad hoc network

DID: The universal id of the destination node in the objective ad hoc network

Rep: A flag, controlling the status of RREP

Flag: A flag, controlling the increment of hop count

Hops: Number of hops from the sender to current node

MsgSize: Size of the message

Sequence: The universal sequence id of the message

BirthTime: The birth time of the message, used to monitor the birth and death of the messge.

RList: Record the list of recipients of the forwarding message.

Node Data Structure

A node in the simulation maintains it position information, serial id, two processing lists, and a routing table as shown in the following:

Xposition: Location information

Yposition: Location information

SerialNum: Sequence number of the node

CurrentList: The list of requests to be processed in the current iteration

NextList: The list of requests to be processed in the next iteration

RoutingTable: The table that is referenced when route the messages

Routing Table Data Structure

The routing table of a node maintains the information that is used in routing a message or maintaining an active route, includes:

NextHop: the successor on the path

HopNum: Hop counts from the sender to this node

Timer: To help decide when the route expires

Active: Indicator of the activeness of the route

SrcPosX: Position info of the sender, for head reduce

SrcPosY: Position info of the sender, for head reduce

LastTime: The last time that a package passed

Degree: Connectivity degree

4.3.3 Description of Simulation Procedure

4.3.3.1 Generating of the Ad Hoc Network

The network is generated randomly for the simulation. It can generate any number of nodes within an arbitrarily determined area with random graph. In this simulation, the network is deployed in an area of $1Km^2$. 50, 100, and 400 nodes are generated in each experiment respectively. The nodes are Brownish moving, and changing direction every 1 millisecond. The speed is set to 1m/s, 10m/s, and 30m/s, in order to simulate merely static, dynamic, and highly dynamic network environment.

4.3.3.2 Generating of the messages

Data Message Generating

The arrival of data is a Poisson process at an average rate of 1 package/second. The average package is set to 1 Mbits/package. If the iteration interval is set to one millisecond, then the possibility of message arrival is 0.001. A random number generator is employed to generate random numbers. At the generation of a message, the message data structure is initialized.

Beacon Message Generating

Once a node in an active path does not hear from its predecessor over a certain time interval, namely the beacon interval, it sends a hello message to beacon it. The beacon interval depends on the average speed of the network. According to different network average speed, 1m/s, 10m/s, 30m/s, the beacon intervals are 100ms, 10 ms, and 3ms respectively. Beacon message is much simpler than the data message, it records only source and destination, and hop count is restricted to be one to prevent this message from going further than one hop.

4.3.3.3 Message Delivery

When a data message is generated, two individual nodes are selected as the source and the destination randomly. The source node searches its routing table to detect if it knows the path to the destination. If yes, then a data package is sent to the next hop toward the destination. Otherwise, the source floods over the network to find a path. Upon receiving a data package, a node checks if it is the recipient. If the node is the recipient, it then issues an acknowledgement to the sender reverse the coming path of the data package. Intermediate nodes only forward data and acknowledgement packets. Once a message is successfully delivered, the recipient will check the incoming message's type to decide what to do next. The node's routing table also has to be updated accordingly. If the node is the destination of the package, it has to decide what to be happening next with the package. For example, if a data package is received and more data packages are waiting, the node will change the message's type to ACK and head it back, vice versa.

4.3.3.4 Loop Freedom

In the path finding, the flood algorithm propagates a Route *Request (RREQ)* from a node to all its neighbors. To prevent loop from happening, the package has a recipient list R_List that records all nodes that has received the message. And the recipient will not hear the same message anymore.

4.3.3.5 Handling Errors

Errors may occur under the following cases:

- **Destination not found**

  The destination has no direct or multi-hop connection with the source. Thus after the *RREQ* has reached all connected nodes, no route reply returns. In the simulation, this situation is not further processed. The data message is not forwarded hence.

- **Path broken**

  The broken of forward or backward route are all considered as path broken. The path broken leads to the data packet or acknowledgement hung at a point and then get lost. If the broken of the path is identified by the beaconing, then a *Route Error (RERR)* packet will send back to the sender and a path finding procedure will be evoked. Otherwise, the package gets lost and the algorithm simulated suffers from the failure.

4.4 Simulation Results and Analysis

In this section we first evaluates the performance of the LOR by comparing with the AODV algorithm. Then, the influence of the network size and mobility are discussed based on experimental results.

4.4.1 Performance evaluation based on comparisons

Network throughput

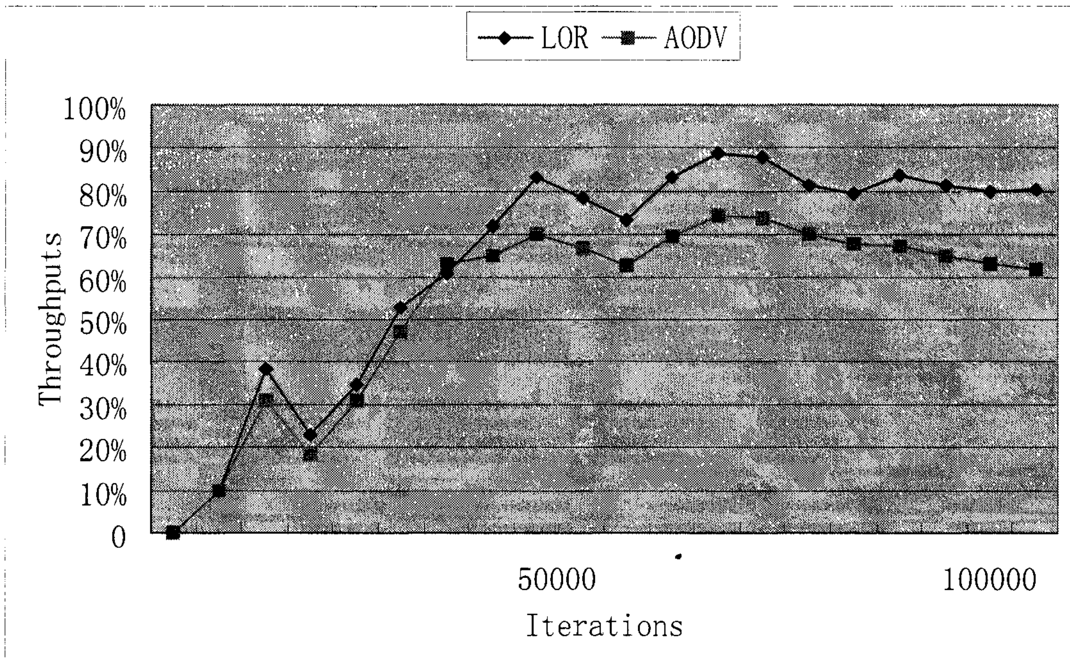

Figure 4-1 Network throughputs

In this experiment, the network throughput is the percentage of all delivered messages over all the messages arrived at the network. Figure 4-1 shows that the LOR achieves a better performance than the AODV algorithm. The LOR tends to keep its throughput around of 80% while the AODV's is around 65%. Here 100% means all 100Mb data is finished transmission in the mean time of 100,000 iterations.

Control Overhead

The programs collect the number of overall control packets generated and the number of overall packets generated in the network. The portion of the control packets in all the packets generated contributes to the control overhead. Figure 4-2 shows the performance of this matrix of the LOR against the AODV algorithm.

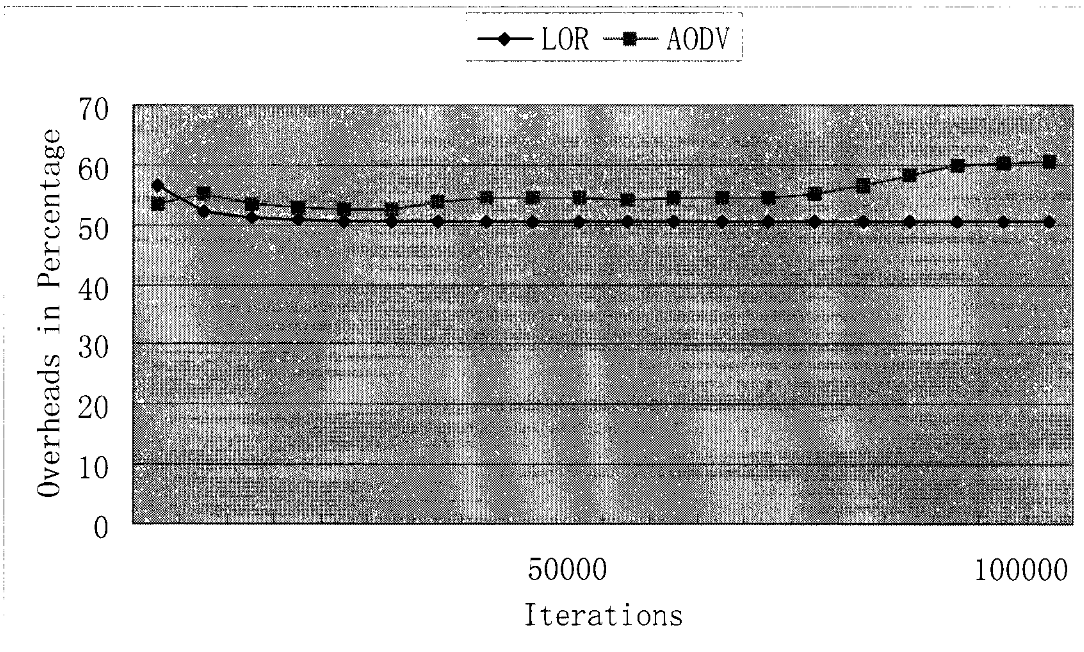

Figure 4-2 Control overheads

It is clearly seen that the LOR has a strictly smaller control overhead than the AODV algorithm soon after the simulation started. The LOR maintains at the level of 50% while the AODV surges and reaches 60% at the end of the 100,000th iteration. This shows that as time goes on, the AODV has to spend more control messages on maintaining a valid route. But the LOR avoid this part of overhead by estimating the *Degree of Connectivity*.

Average End-to-End Delay

It is another important index in performance evaluation. Figure 4-4 shows that the two algorithms are merely the same on this index. That is because the LOR is not devoted in reducing the average end-to-end delay. And in some circumstances there existed the potentiality of increasing the delay. For example, the restricted flood does not lead to a shorter path than a full flood, but it does not hit, eventually the delay time increases. But, as a balance, the local repair strategy and route reduction strategy potentially helps in decreasing the delay time. As the network follows a forward-and-wait strategy, which means the next package is transmitted only after the ACK of the previous package is received, the average delays are much greater, around 11.5 seconds per 1Mb data.

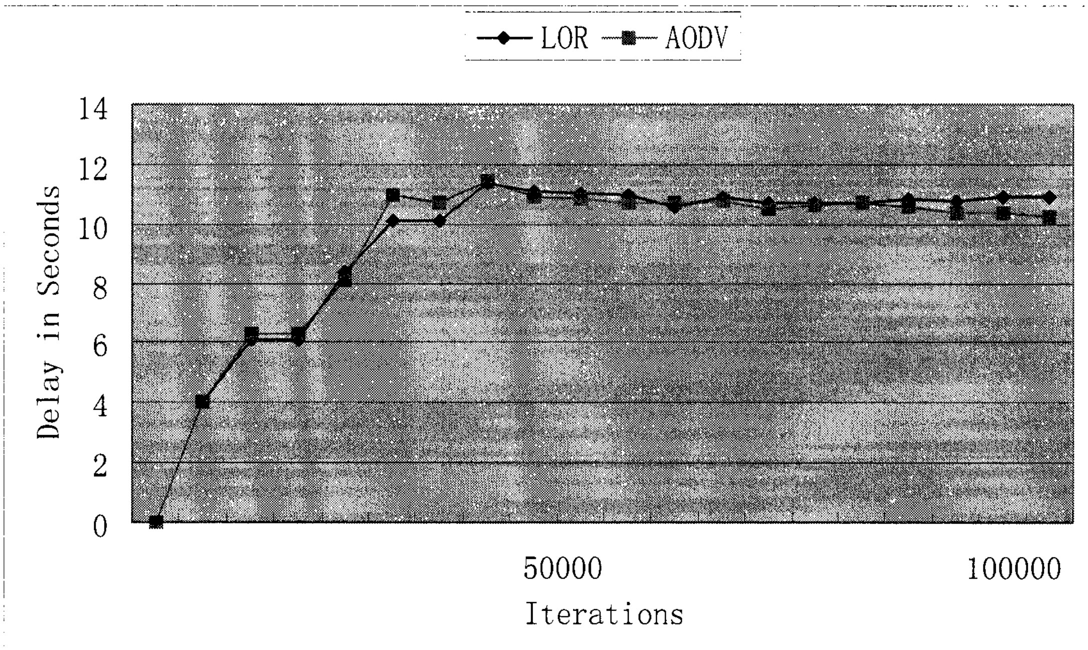

Figure 4-3 Average End-to-end Delay

Power Consumption Ratio

This ratio measures the consumptions of power on watts per Kb message. Assume that each transmit consumes 1 watt of battery power and could transmit at maximum of 1Kb message. Figure 4-3 indicates that the LOR has a much lower ratio than the AODV algorithm. The LOR consumes around 11.5 watts power transmitting 1Kb message, while the AODV consumes 13.5 watts. The LOR demonstrates a performance of about 15% power saving in this experiment.

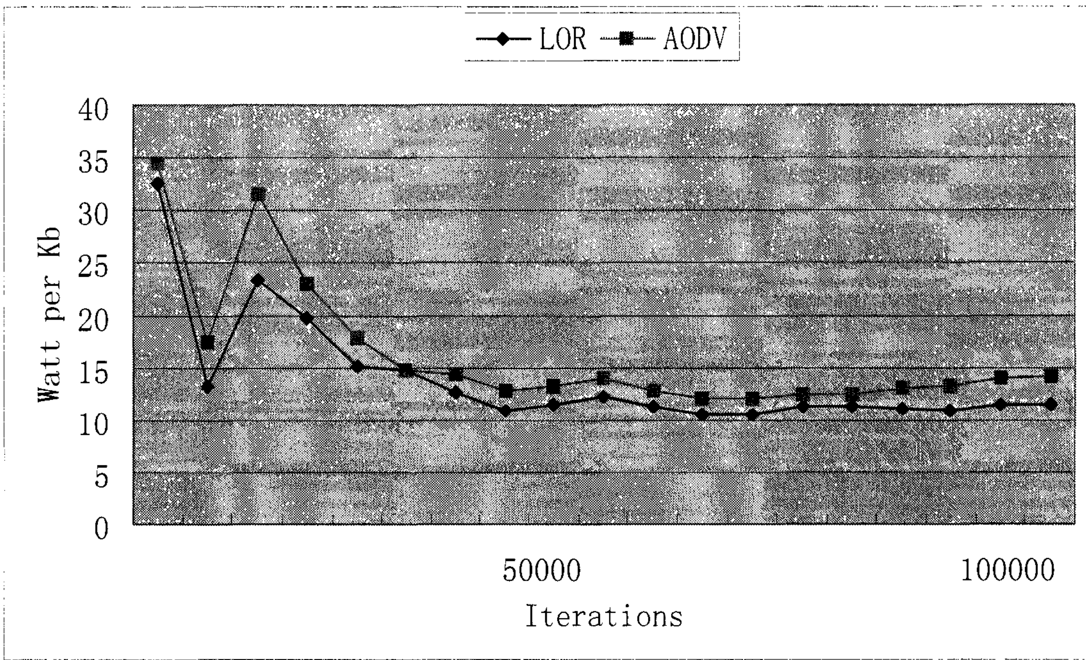

Figure 4-4 Power Consumption Ratios

4.4.2 Impacts of Velocity on Performances

Usually an ad hoc network moves toward a destination in one or more groups. Mid that even the network is moving at a very high absolute speed, for example 100KM/h, the relative speeds of nodes in it is not that high. Thus the speeds ranked as low, middle, and high in the experiments are 1m/s, 10m/s, and 30m/s. The data collected falls on the iteration 80,000 of each experiment, when the networks are stable enough.

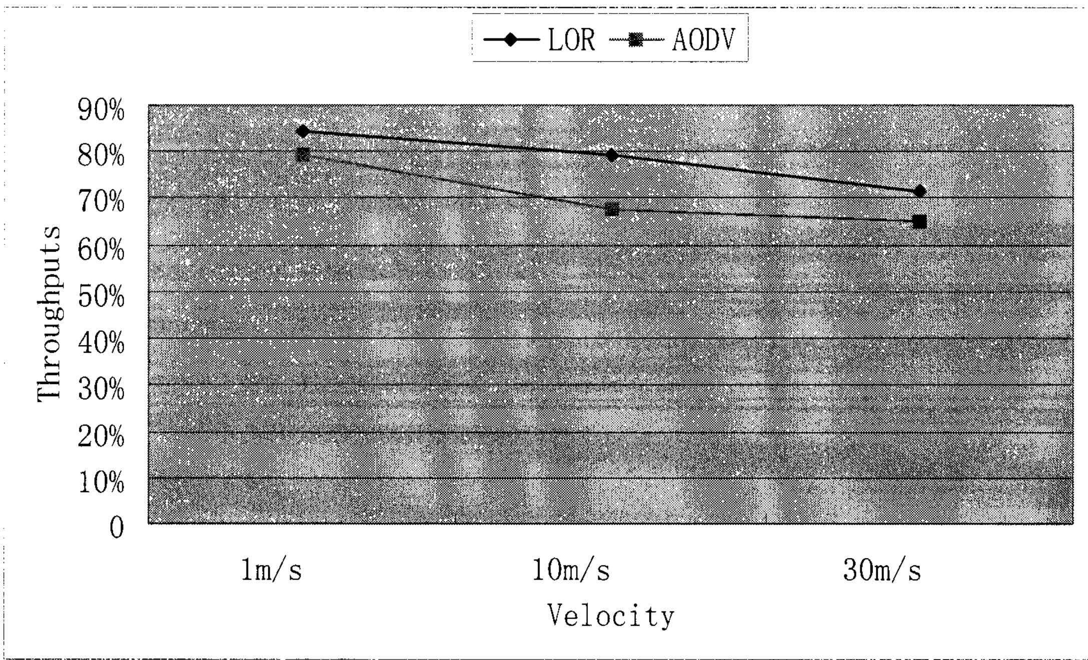

Figure 4-5 Network throughputs under low, medium, and high mobility

Figure 4-5 shows the throughputs of the LOR and the AODV algorithm when the network nodes have average relative speeds of 1m/s, 10m/s, and 30m/s. The results lines are descending as expected when the speed increases. It is quite clear that the LOR has strictly higher throughputs in all three circumstances

Consequently, the influence of speed is also shown in Figure 4-6, 4-7, and 4-8. In Figure 4-6, we can see the LOR keeps a constant ratio of control overhead under low, medium, and high speeds. The AODV algorithm shows a liner increment at the low and medium speed, but becomes less efficient than the LOR when comes to the highly dynamic nature.

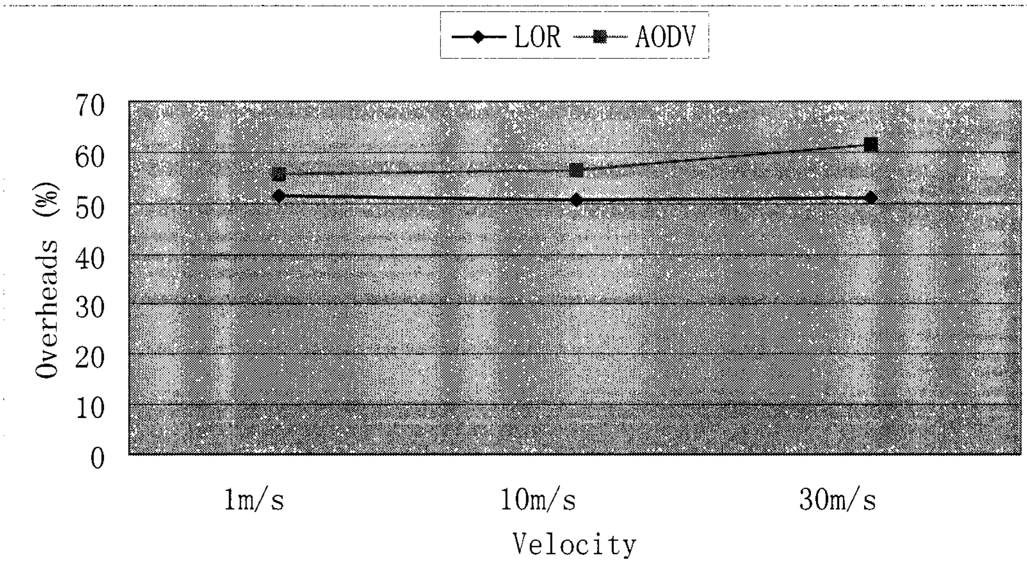

Figure 4-6 Impacts of speed on Control overheads

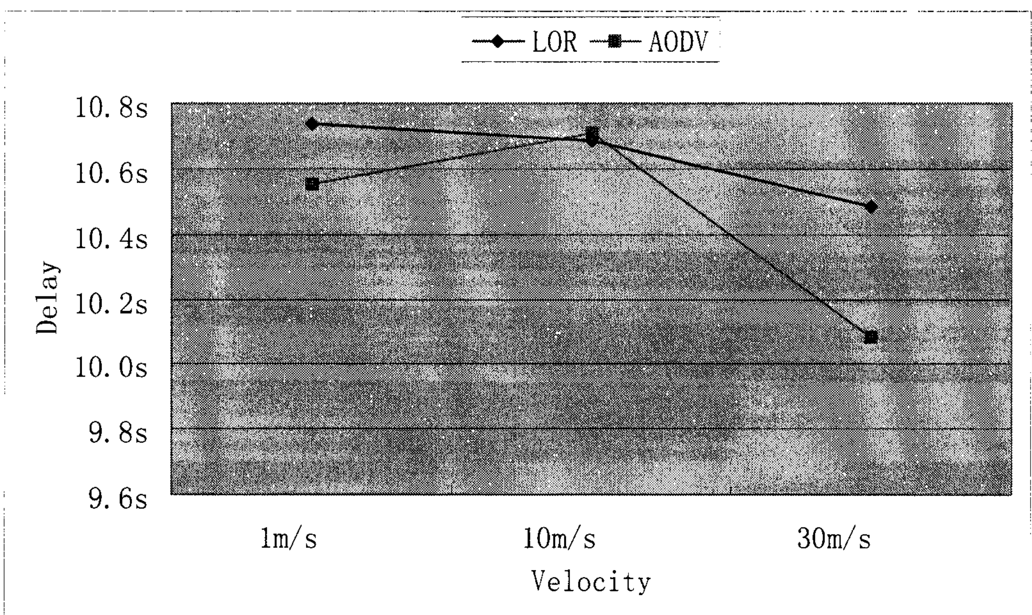

Figure 4-7 Influences of mobility on average delays

In Figure 4-7 we see a very interesting result – the average delay of the AODV algorithm achieve a very optimum average end-to-end delay when the network is moving at a very high speed. The contrast is so significant that its counterpart, the LOR, almost remains a liner decrement when speed surges. But, if we study the definition of average end-to-end delay, we could find that it is not difficult to interpret this result. As the routes become unreliable under a highly dynamic nature, packages that travel a longer path is more likely to be lost. Thus, when calculating average end-to-end delay, more packages that travel shorter paths contribute more to the final result. Hence, both algorithms experience lower average delays. But, things turn to be more difficult for the AODV routing to deliver packets farther than the LOR. This leads to the above interesting result.

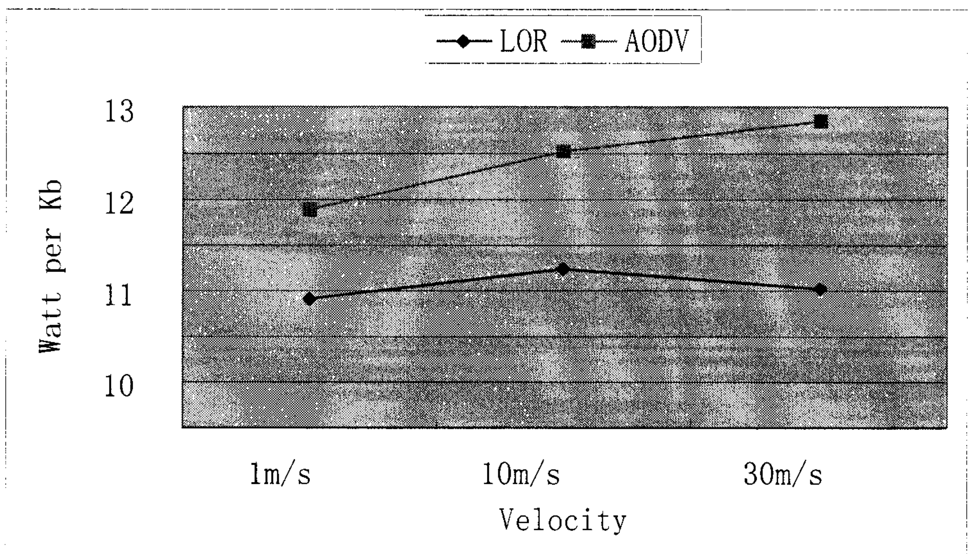

Figure 4-8 Power consumption ratios under different speeds

Figure 4-8, together with Figure 4-4, shows the LOR is strictly less power consuming than the AODV routing.

4.4.3 Impacts of network size on performances

In the beginning, the ad hoc networks are mostly small or medium sized networks, as the purposes of such networks are for the use of military or rescuer. More recently, the use of ad hoc networks in the commercial filed raise a possibility to build temporary ad hoc networks that sized large. Thus ad hoc routing algorithms are more and more required to scale through all sizes, not just small and medium size.

Experiments on the performance of the LOR are also taken at network of small, medium, and large sizes. In the simulations, experiments are made on 50, 100, and 400, which stand for small, medium, and large networks, respectively.

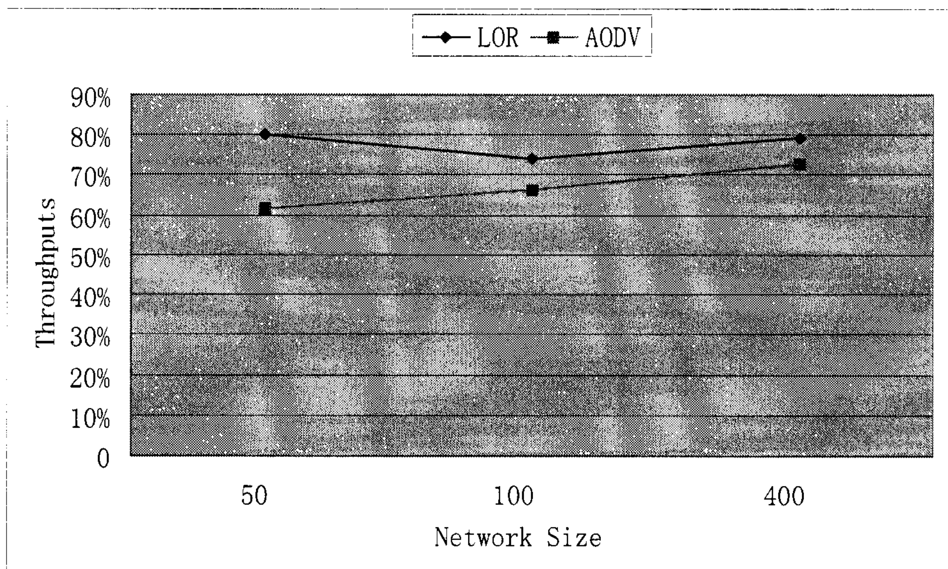

Figure 4-9 Throughputs at network size 50, 100, and 400

Figure 4-9 shows the influence of the network size on the network throughputs. The LOR demonstrates an optimum performance at any size networks. It has 19%, 9%, and 8% higher throughputs than the AODV algorithm. However, with the increment of the network size, the AODV's throughput is improving. But the LOR possesses strictly better performance on this index.

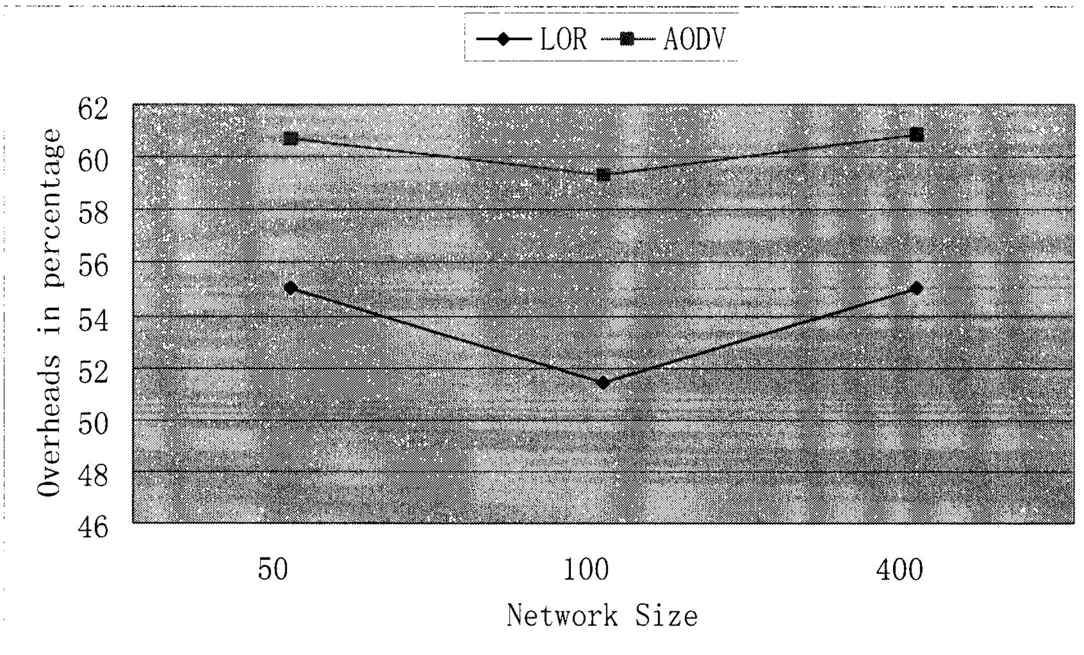

Figure 4-10 Control Overheads at Network Size 50, 100, and 400

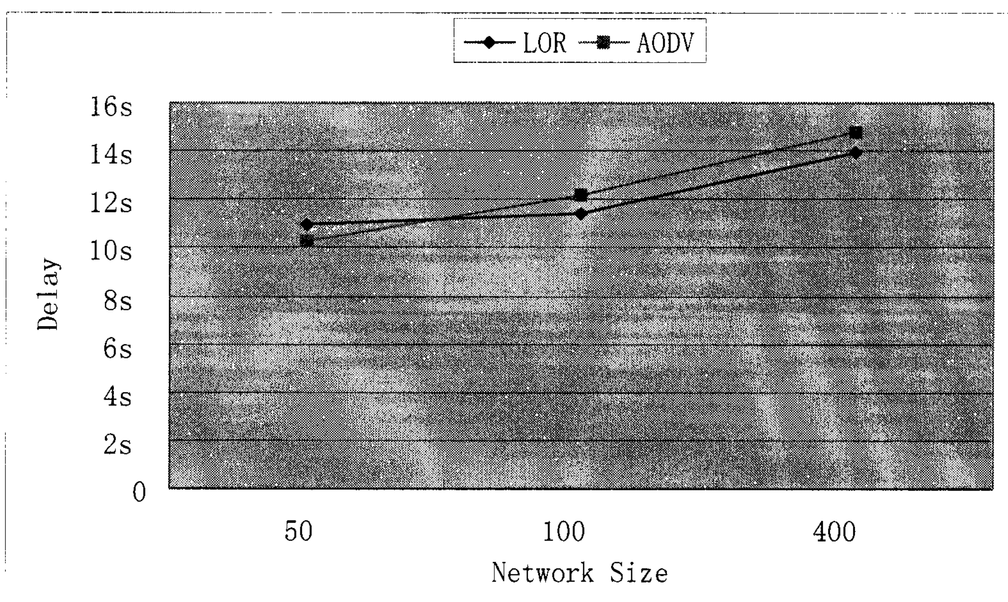

Figure 4-11 Average Delays at Network Size 50, 100, and 400

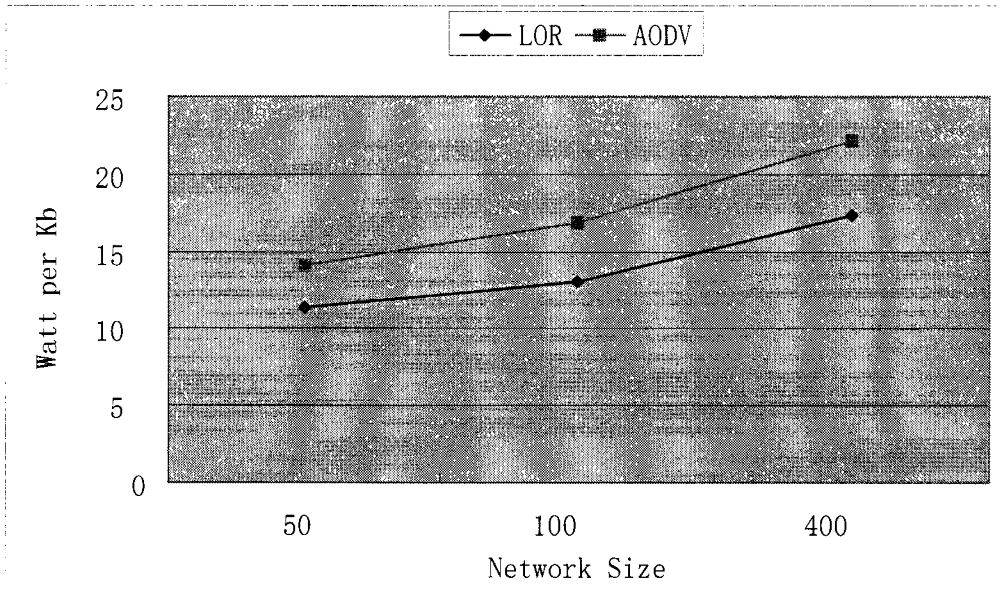

Figure 4-12 Impact of Network Size on Power Consumption

Figure 4-10 to Figure 4-12 show the other three parameters examined in the simulation. Figure 4-10 tells that the LOR always costs less control overheads than the AODV. Accordingly, in Figure 4-12, the LOR spends less time on transmitting 1Kb data. However, Figure 4-11 shows the two algorithms have nearly the same average delays at different network sizes. But, the LOR's Hop Reduce strategy and Local Repair strategy fine tune its performance. Hence at a medium or larger size, the LOR turns to have a slightly shorter average delay than the AODV.

Chapter 5
Conclusions

This work presents a novel location based ad hoc routing algorithm, the Location-Enhanced On-demand Routing (LOR) algorithm. The LOR is unique from contemporary location based ad hoc routing algorithms – it proposes to use local position to take the place of global position information. The using of local position mechanism leads to a series of changes on network coordinate computing, position information synchronization, and route decision. The novel algorithm demonstrates a promising performance in reducing network control overheads.

In this chapter, we review the syntheses of work and contributions, limitations of research, and future research directions.

5.1 Syntheses of Work and Contributions

Previsouly we addressed the limitation of contemporary location based ad hoc routing algorithms, and proposed that the novel algorithm should posses 6 properties:

- Based on local position,
- GPS independent,
- Synchronize position information only on-demand,
- Reduce network control overhead,
- Power conservation, and
- Improve network performance.

Through the description of the LOR algorithm and the simulation results we can see that these goals have been achieved. The LOR employs smart antennas to position mobile nodes, applies the GPS-free ad hoc positioning algorithm [3] to calculate local network coordinate, and synchronizes local position information upon request only. Thus the

LOR is truly freed from the limitations of GPS services. Since it does neither beacons periodically like non-location-based on-demand algorithms, nor queries the GPS services and then synchronizes the position obtained according to a fixed time interval, it has successfully reduced network control overheads by 10%. Discount the power saving characteristic of the smart antennas, the algorithm itself is tested to be more power conservative.

In the simulation, the AODV algorithm is compared as a reference for the performance. The two proposed routing schemes are compared in a variety of mobility, network size, and traffic load conditions. The simulation model was well validated and especially designed to be unbiased, so that objective conclusions concerning the two paradigms as general approaches may be derived. It was anticipated that the LOR would outperform the objective on-demand routing in all cases.

The experimental results show that the LOR succeed in reducing the overhead of routing, improving the network throughput, and preserving the power. This is achieved at no expense in terms of average end-to-end delay. Statistically, the LOR demonstrates 15% higher in average network throughput, 7% lower in network control overhead, and 20% power saving in baseline performance evaluation. And it outperforms the objective on-demand algorithm in all conditions designed in this simulation.

5.2 Limitations of the Research

In this work, we assume that the positioning mechanism is accurate enough to fulfill our needs in location. But the accuracy of smart antenna array positioning has limitations. The impact of accuracy on positioning is not studied in detail. This is a major limitation of our research.

The second limitation is that we ignored the computing overhead generated by the GPS-free ad hoc positioning algorithm. This algorithm is a complex algorithm that generates computing overhead on mobile terminal. For example, it could take many more CPU clock cycles on location computing hence decrease the performance of a terminal. And it is also possible that more power is consumed on computing. The following two reasons let us neglect the impact. Firstly, we research the network as an object, not a single terminal. Secondly, the above problems will become trivial with constant improvement of performance on computing technologies.

5.3 Future Research Directions

In Chapter 3, we addressed the most desired properties of ad hoc routing algorithms as:

- Distributed operation
- Loop-free transmission
- Scalability
- Multicast
- Unidirectional link support
- Dynamic route refinement
- Security
- Power conservation
- Quality of Service support

The LOR inherits from its prototype AODV, many of these properties, such as Loop Freedom, Distributed Operation, and Multicast. By taking the advantage of location, the LOR also has improved the Scalability and Power Conservation. We also notice that the LOR, as a local position based algorithm, is capable of taking the advantage of position information to dynamically refine route decision, and support QoS routing. These are left as our future research objectives.

BIBLIOGRAPHY

[1] M. Abolhasan, T. Wysocki, E. Dutkiewicz. "A review of routing protocols for mobile ad hoc networks". *Ad Hoc Networks, Volume 2, Issue 1*, January 2004, pp. 1-22

[2] C. Adjih, E. Baccelli, P. Jacquet. "Link state routing in wireless ad-hoc networks". *Military Communications Conference, 2003. MILCOM 2003. IEEE ,Volume 2* , 13-16 Oct. 2003, pp.1274 – 1279

[3] S. Capkun, M. Hamdi, J.-P. Hubaux. "GPS-free positioning in mobile ad-hoc networks". *Proceedings of the 34th Annual Hawaii International Conference on System Sciences*, 2001, p 10 pp.

[4] M. S.Corson, A. Ephremides. "A distributed routing algorithm for mobile wireless networks". *Wireless Networks, volume 1, no. 1*, 1995, pp. 61-81

[5] B. G. Evans, K. Baughan. "Visions of 4G". *Electronics & Communication Engineering Journal, volume 12, no. 6*, Dec. 2000, pp. 293-303

[6] S. Gupte, M. Singhal. "Secure routing in mobile wireless ad hoc networks". *Ad Hoc Networks, Volume 1, Issue 1*, July 2003, pp. 151-174

[7] Z. J. Haas. "A new routing protocol for the reconfigurable wireless networks". *1997 IEEE 6th International Conference on Universal Person Communications Record. Bridging the Way to the 21st Century, ICUPC '97. Conference Record (Cat. No.97TH8255), Volume 2*, 1997, pt. 2, pp. 562-6

[8] Z.J. Haas, M.R. Pearlman, P. Smar "Internet Draft, draft-ietf-manet-zone-zrp-04.txt", July 2002.

[9] Imrich Chlamtac, Marco Conti, Jennifer J.-N. Liu. "Mobile ad hoc networking: imperatives and challenges". *Ad Hoc Networks, Volume 1, Issue 1,* July 2003, pp. 13-64

[10] P. Jacquet, P. Muhlethaler, T. Clausen, A. Laouiti, A. Qayyum, L. Viennot. "Optimized link state routing protocol for ad hoc networks". *IEEE Proceedings IEEE International Multi Topic Conference 2001. IEEE INMIC 2001. Technology for the 21st Century (Cat. No.01EX557)*, 2001, pp. 62-8

[11] Young-Bae Ko, Nitin H. Vaidya. "Location-aided routing (LAR) in mobile ad hoc networks". *Wireless Networks, Volume 6*, Sep, 2000, pp. 307-321

[12] M. Mauve, A. Widmer, H. Hartenstein. "A survey on position-based routing in mobile ad hoc networks". *IEEE Network, volume 15, no. 6*, Nov.-Dec. 2001, pp. 30-9

[13] D. Niculescu, B. Nath. "Ad hoc positioning system (APS)". *Conference Record / IEEE Global Telecommunications Conference, Volume 5*, 2001, pp. 2926-2931

[14] D. Niculescu, B. Nath. "Ad hoc positioning system (APS) using AOA". *Proceedings - IEEE INFOCOM, volume 3*, 2003, pp. 1734-1743

[15] D. Niculescu, Bardi Nath. "Localized positioning in ad hoc networks". *Proceedings of the First IEEE International Workshop on Sensor Network Protocols and Applications*, 11 May 2003, pp. 42 - 50

[16] D. Niculescu, Bardi Nath. "Position and orientation in ad hoc networks". *Ad Hoc Networks, Volume 2, Issue 2*, April 2004, pp. 133-151

[17] P. Papadimitratos, Z. J. Haas. "Secure message transmission in mobile ad hoc

networks". *Ad Hoc Networks, Volume 1, Issue 1*, July 2003, pp. 193-209

[18] C. E. Perkins, Elizabeth M. Royer, Samir R. Das. "Ad hoc on-demand distance vector routing". *Proceedings IEEE WMCSA '99, Volume 3, New Orleans, LA.*, pp. 90-100

[19] Dmitri D. Perkins, Herman D. Hughes. "A survey on quality-of-service support for mobile ad hoc networks". *Wireless Communications and Mobile Computing, volume 2, n 5*, August, 2002, pp. 503-513

[20] K. S. Phanse, L. A. DaSilva. "Addressing the requirements of QoS management for wireless ad hoc networks". *Computer Communications, volume 26, no. 12*, 21 July 2003, pp. 1263-73

[21] A. Qayyum, L. Viennot, A. Laouiti. "Multipoint relaying for flooding broadcast messages in mobile wireless networks". *Proceedings of the 35th Annual Hawaii International Conference on System Sciences*, 2002. HICSS., 7-10 Jan. 2002 , pp. 3866 – 3875

[22] T. S. Rappaport, J. H. Reed, B. D. Woerner. "Position location using wireless communications on highways of the future". *IEEE Communications Magazine, volume 34, no. 10*, Oct. 1996, pp. 33-41

[23] D. Remondo, I. G. Niemegeers. "Ad hoc networking in future wireless communications". *Computer Communications, volume 26, no. 1*, 1 Jan. 2003, pp. 36-40

[24] P. Sholander, A. Yankopolus, P. Coccoli, S. S. Tabrizi. "Experimental comparison of hybrid and proactive manet routing protocols". *Proceedings of IEEE Military Communications Conference MILCOM, volume 1*, 2002, pp. 513-518

[25] D. R. Van Rheeden, S. C. Gupta. "A single base station position location approach for enhanced-911". *VTC '98. 48th IEEE Vehicular Technology Conference. Pathway to a Global Wireless Revolution (Cat. No.98CH36151), Volume 3*, 1998, pt. 3, pp. 2555-9

[26] T. Wu, C. Huang, H. Chao. "A survey of Mobile IP in cellular and Mobile Ad-Hoc Network environments". *Ad Hoc Networks, In Press, Corrected Proof*, Available online 20 December 2003,

[27] Z. Ye, S. V. Krishnamurthy, S. K. Tripathi. "A routing framework for providing robustness to node failures in mobile ad hoc networks". *Ad Hoc Networks, Volume 2, Issue 1*, January 2004, pp. 87-107

[28] X. Zhang, L. Jacob. "Multicast zone routing protocol in mobile ad hoc wireless networks". *Proceedings 28th Annual IEEE International Conference on Local Computer Networks - LCN 2003. Held in conjunction with the Workshop on High-Speed Local Networks (HSLN) and Workshop on Wireless Local Networks (WLN 2003)*, 2003, pp. 150-9

[29] C. E. Perkins. *Ad Hoc Networking*. Addison Wesley, 2000

[30] Q. Li, Q., J. Aslam, and D. Rus. "On-line power-aware routing in wireless ad-hoc networks", in *Proc. 6th Annual ACM/IEEE MobiCom Conference*, 2001

[31] R. Ramanathan, M. Steenstrup. "A survey of routing techniques for mobile communication networks", *ACM/Baltzer Mobile Networks and Applications, volume1, no. 2*, 1996, pp. 89-103

[32] T. Camp, J. Boleng, V. Davies. "A survey of mobile models for ad hoc research",

Wireless Communications & Mobile Computing (WCMC): Special issue on Mobile Ad Hoc Networking: Research, Trends, and Applications, 2002

[33] J. C. Liberti and T. S. Rappaport, *Smart Antennas for Wireless Communications: IS-95 and Third-Generation CDMA Applications*, Prentice Hall, NJ, USA. 1999, ISBN 0-13-719287-8.

[34] B. Ludden *et al.*, "Mobile Subscriber Location using Handset-Assisted Positioning Techniques," *3rd European Personal mobile Communications Conference EPMCC '99*, Paris, France, Mar. 911, 1999, pp. 6772

[35] A. Einstein. *Investigation on the Theory of the Brown Movement.* Dover Pubns, 1956

APPENDICES

1. AODV Algorithm Simulation Results

Network Size = 50 Speed = 10 m/s Traffic Load = 1M/s Area = 1Km^2

Power Ratio (Watt/Kb)	Throughput (%)	Overhead (%)	Average Delay (ms)
34..424	1	55.194	4004
17369	4	53.5955	6314.25
31.624	4	52.998	6314.25
22.991	9	52.5824	8086
17.774	16	52.7318	10987.2
14.695	24	54.0526	10706.5
14.283	28	54.6059	11437.1
12.748	33	54.6575	10910.3
13.169	34	54.481	10831.9
13.978	35	54.2479	10699.5
12.901	41	54.4889	10697
12.134	46	54.6809	10764
12.141	48	54.6462	10547.6
12.487	49	55.232	10626.1
12.523	52	56.604	10710.5
13.097	53	58.3376	10610.5
13.181	56	59.9547	10382.9
13.985	56	60.4467	10382.9
14.114	59	60.7192	10265.6

2. LOR Algorithm Simulation Results

Network Size = 50 Speed = 10 m/s Traffic Load = 1M/s Area = $1Km^2$

Power Ratio (Watt/Kb)	Throughput (%)	Overhead (%)	Average Delay (ms)
32.543	1	52.0972	4004
13.202	5	51.3308	6099.4
23.384	5	51.043	6099.4
19.681	10	50.7233	8350
15.034	18	50.5831	10113.7
14.655	23	50.526	10144.6
12.639	31	50.526	11390.1
10.974	39	50.5456	11094.1
11.489	40	50.6262	11076.8
12.331	41	50.5866	10958.6
11.231	49	50.5567	10584.8
10.527	55	50.5567	10892.5
10.594	57	50.5551	10720.9
11.255	57	50.6546	10720.9
11.250	61	50.6309	10685.5
11.020	66	50.617	10873.2
10.967	70	50.617	10779.8
11.552	71	50.5964	10919
11.404	77	50.5777	10910.8